ANL/ESD/05-3

# Operating Manual for GREET: Version 1.7

prepared by
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# Operating Manual for GREET: Version 1.7

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# Acronyms and Abbreviations

| | |
|---|---|
| AFV | Alternative fuel vehicle |
| ANL | Argonne National Laboratory |
| AVT | Advanced vehicle technology |
| BD | biodiesel |
| BD20 | mixture of 20% biodiesel and 80% diesel by volume |
| CARFG | California reformulated gasoline |
| CC | combined cycle |
| CD | conventional diesel |
| CG | conventional gasoline |
| $CH_4$ | methane |
| CI | compression-ignition |
| CIDI | compression-ignition direct-injection |
| CNG | compressed natural gas |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| DDGS | distillers' dried grains and solubles |
| DME | dimethyl ether |
| DMP | dry milling plant |
| DOE | U.S. Department of Energy |
| EF | emission factor |
| EIA | Energy Information Administration |
| EPA | U.S. Environmental Protection Agency |
| ETBE | ethyl tertiary butyl ether |
| EtOH | ethanol |
| EV | electric vehicle |
| E10 | mixture of 10% ethanol and 90% gasoline by volume |
| E85 | mixture of 85% ethanol and 15% gasoline by volume |
| E90 | mixture of 90% ethanol and 10% gasoline by volume |
| ED10 | mixture of 10% ethanol and 90% diesel by volume |
| FCV | fuel cell vehicle |
| FG | flared gas |
| FTD | Fischer-Tropsch diesel |
| FTN | Fischer-Tropsch naphtha |
| GC | grid-connected |
| $GH_2$ | gaseous hydrogen |
| GHG | greenhouse gas |
| GI | grid-independent |
| GREET | **G**reenhouse Gases, **R**egulated **E**missions, and **E**nergy Use in **T**ransportation |
| GTCC | gas turbine combined cycle |
| GUI | graphical user interface |
| GVW | gross vehicle weight |
| GWP | global warming potential |
| $H_2$ | hydrogen |
| HEV | hybrid electric vehicle |
| HHV | higher heating value |
| HTGR | high-temperature gas-cooled reactor |
| ICE | internal combustion engine |
| IGCC | integrated gasification combined cycle |

| | |
|---|---|
| IPCC | Intergovernment Panel on Climate Change |
| LDT | light-duty truck |
| LG | landfill gas |
| $LH_2$ | liquid hydrogen |
| LHV | lower heating value |
| LNG | liquefied natural gas |
| LPG | liquefied petroleum gas |
| LSD | low-sulfur diesel |
| LT | long-term |
| LWR | light water reactor |
| MeOH | methanol |
| MTBE | methyl tertiary butyl ether |
| M85 | fuel mixture of 85% methanol and 15% gasoline by volume |
| M90 | fuel mixture of 90% methanol and 10% gasoline by volume |
| N | nitrogen |
| $N_2O$ | nitrous oxide |
| NA | North American |
| NE U.S. | North-Eastern United States |
| NG | natural gas |
| NGCC | natural gas combined cycle |
| NNA | non-North American |
| $NO_X$ | nitrogen oxides |
| $O_2$ | oxygen |
| PC | passenger car |
| $PM_{10}$ | particulate matter with aerodynamic diameter of 10 micrometers or less |
| PSAT | Powertrain System Analysis Toolkit (transient vehicle simulation software) |
| PTW | pump-to-wheels |
| RBAEF | Role of Biomass in America's Energy Future |
| RFG | reformulated gasoline |
| S | sulfur |
| SI | spark-ignition |
| SIDI | spark-ignition direct-injection |
| SMR | steam methane reforming |
| $SO_2$ | sulfur dioxide |
| $SO_X$ | sulfur oxides |
| SWU | separative work units |
| T&D | transportation and distribution |
| TAME | tertiary amyl methyl ether |
| TCWC | thermo-chemical water cracking |
| TE | total energy |
| TS | time series |
| VMT | vehicle miles traveled |
| VOC | volatile organic compound |
| VRI | Vishwamitra Research Institute |
| WMP | wet milling plant |
| WTP | well-to-pump |
| WTW | well-to-wheels |

# 1. GREET Model Structure

Since the release of **G**reenhouse Gases, **R**egulated **E**missions, and **E**nergy Use in **T**ransportation (GREET) model version 1.6 in 2001, Argonne National Laboratory has expanded, updated, and upgraded the model. The newly released version of the GREET model (version 1.7) consists of 27 Microsoft® Excel sheets; each of which is briefly described in this section. More than 90 fuel production pathways and 70 vehicle/fuel systems are shown in Tables 1.1 and 1.2, respectively.

**TABLE 1.1 Fuel Production Pathway Options Included in GREET 1.7**

| Feedstock | Fuel |
|---|---|
| Petroleum | 1) Conventional gasoline (CG) |
| | 2) Reformulated gasoline (RFG) |
| | 3) California reformulated gasoline (CARFG) |
| | 4) Conventional diesel (CD) |
| | 5) Low-sulfur diesel (LSD) |
| | 6) Liquefied petroleum gas (LPG) |
| | 7) Crude naphtha |
| Natural Gas (NG) | 8) North American natural gas to compressed natural gas (NA NG to CNG) |
| | 9) Non-North American natural gas to compressed natural gas (NNA NG to CNG) |
| | 10) Non-North American flared gas to compressed natural gas (NNA FG to CNG) |
| | 11) North American natural gas to liquefied natural gas (NA NG to LNG) |
| | 12) Non-North American natural gas to liquefied natural gas (NNA NG to LNG) |
| | 13) Non-North American flared gas to liquefied natural gas (NNA FG to LNG) |
| | 14) North American natural gas to methanol (NA NG to MeOH) |
| | 15) Non-North American natural gas to methanol (NNA NG to MeOH) |
| | 16) Non-North American flared gas to methanol (NNA FG to MeOH) |
| | 17) North American natural gas to Fischer-Tropsch diesel (NA NG to FTD) |
| | 18) Non-North American natural gas to Fischer-Tropsch diesel (NNA NG to FTD) |
| | 19) Non-North American flared gas to Fischer-Tropsch diesel (NNA FG to FTD) |
| | 20) North American natural gas to Fischer-Tropsch naphtha (NA NG to FTN) |
| | 21) Non-North American natural gas to Fischer-Tropsch naphtha (NNA NG to FTN) |
| | 22) Non-North American flared gas to Fischer-Tropsch naphtha (NNA FG to FTN) |
| | 23) North American natural gas to gaseous hydrogen (NA NG to $GH_2$) in central plants |
| | 24) Non-North American natural gas to gaseous hydrogen (NNA NG to $GH_2$) in central plants |
| | 25) Non-North American flared gas to gaseous hydrogen (NNA FG to $GH_2$) in central plants |
| | 26) North American natural gas to gaseous hydrogen (NA NG to $GH_2$) at refueling stations |
| | 27) Non-North American natural gas (NNA NG) to compressed hydrogen at refueling stations |
| | 28) Non-North American flared gas to gaseous hydrogen (NNA FG to $GH_2$) at refueling stations |

**TABLE 1.1 Fuel Pathway Options Included in GREET 1.7 (Cont'd)**

| Feedstock | Fuel |
|---|---|
| | 29) North American natural gas to liquid hydrogen (NA NG to $LH_2$) in central plants |
| | 30) Non-North American natural gas to liquid hydrogen (NNA NG to $LH_2$) in central plants |
| | 31) Non-North American flared gas to liquid hydrogen (NNA FG to $LH_2$) in central plants |
| | 32) North American natural gas to liquid hydrogen (NA NG to $LH_2$) at refueling stations |
| | 33) Non-North American natural gas to liquid hydrogen (NNA NG to $LH_2$) at refueling stations |
| | 34) Non-North American flared gas to liquid hydrogen (NNA FG to $LH_2$) at refueling stations |
| | 35) North American natural gas to dimethyl ether (NA NG to DME) |
| | 36) Non-North American natural gas to dimethyl ether (NNA NG to DME) |
| | 37) Non-North American flared gas to dimethyl ether (NNA FG to DME) |
| | 38) North American natural gas to liquefied petroleum gas (NA NG to LPG) |
| | 39) Non-North American natural gas to liquefied petroleum gas (NNA NG to LPG) |
| Landfill gas (LG) | 40) Landfill gas to methanol (LG to MeOH) |
| Biomass | 41) Corn to ethanol (EtOH) in dry milling plants (DMP) |
| | 42) Corn to ethanol (EtOH) in wet milling plants (WMP) |
| | 43) Herbaceous biomass to ethanol (EtOH) |
| | 44) Woody biomass to ethanol (EtOH) |
| | 45) Herbaceous biomass to methanol (MeOH) |
| | 46) Woody biomass to methanol (MeOH) |
| | 47) Herbaceous biomass to Fischer-Tropsch diesel (FTD) |
| | 48) Woody biomass to Fischer-Tropsch diesel (FTD) |
| | 49) Herbaceous biomass to dimethyl ether (DME) |
| | 50) Woody biomass to dimethyl ether (DME) |
| | 51) Herbaceous biomass to gaseous hydrogen ($GH_2$) in central plants |
| | 52) Woody biomass to gaseous hydrogen ($GH_2$) in central plants |
| | 53) Herbaceous biomass to liquid hydrogen ($LH_2$) in central plants |
| | 54) Woody biomass to liquid hydrogen ($LH_2$) in central plants |
| | 55) Soybean to biodiesel (BD) |
| Solar | 56) To gaseous hydrogen ($GH_2$) in central facilities via photovoltaics |
| | 57) To liquid hydrogen ($LH_2$) in central facilities via photovoltaics |
| Nuclear | 58) To gaseous hydrogen ($GH_2$) in central plants via thermo-chemical water cracking |
| | 59) To liquid hydrogen ($LH_2$) in central plants via thermo-chemical water cracking |
| | 60) To gaseous hydrogen ($GH_2$) in central plants via high-temperature electrolysis |
| | 61) To liquid hydrogen ($LH_2$) in central plants via high-temperature electrolysis |
| Coal | 62) To gaseous hydrogen ($GH_2$) in central plants |
| | 63) To liquid hydrogen ($LH_2$) in central plants |

**TABLE 1.1 Fuel Pathway Options Included in GREET 1.7 (Cont'd)**

| Feedstock | Fuel |
|---|---|
| 64) Coal | To electricity |
| 65) Natural Gas | |
| 66) Residual oil | |
| 67) Biomass | |
| 68) Nuclear | |
| 69) Renewables | |
| 70) U.S. electricity generation mix via electrolysis at refueling stations | To gaseous hydrogen ($GH_2$) |
| 71) California electricity generation mix via electrolysis at refueling stations | |
| 72) North-Eastern United States (NE U.S.) electricity generation mix via electrolysis at refueling stations | |
| 73) Coal-based electricity via electrolysis at refueling stations | |
| 74) Residual-oil-based electricity via electrolysis at refueling stations | |
| 75) Natural-gas (NG)-fired boiler electricity via electrolysis at refueling stations | |
| 76) Natural gas (NG) combined-cycle (CC)-based electricity via electrolysis at refueling stations | |
| 77) Nuclear electricity via electrolysis at refueling stations | |
| 78) Hydroelectric power via electrolysis at refueling stations | |
| 79) Ethanol (EtOH) via reforming at refueling stations | |
| 80) Methanol (MeOH) via reforming at refueling stations | |
| 81) U.S. electricity generation mix via electrolysis at refueling stations | To liquid hydrogen ($LH_2$) |
| 82) California electricity generation mix via electrolysis at refueling stations | |
| 83) North-Eastern United States (NE U.S.) electricity generation mix via electrolysis at refueling stations | |
| 84) Coal-based electricity via electrolysis at refueling stations | |
| 85) Residual-oil-based electricity via electrolysis at refueling stations | |
| 86) Natural-gas (NG)-fired boiler electricity via electrolysis at refueling stations | |
| 87) Natural gas combined-cycle (CC)-based electricity via electrolysis at refueling stations | |
| 88) Nuclear electricity via electrolysis at refueling stations | |
| 89) Hydroelectric power via electrolysis at refueling stations | |
| 90) Ethanol (EtOH) via reforming at refueling stations | |
| 91) Methanol (MeOH) via reforming at refueling stations | |

**TABLE 1.2 Vehicle/Fuel Systems Included in GREET 1.7**

| Vehicle Technology | Fuel |
|---|---|
| Spark-ignition (SI) engine vehicles | 1) Conventional gasoline (CG) |
| | 2) Reformulated gasoline (RFG) |
| | 3) California reformulated gasoline (CARFG) |
| | 4) Compressed natural gas (CNG) (bi-fuel) |
| | 5) Compressed natural gas (CNG) (dedicated) |
| | 6) Fuel mixture of 85% methanol and 15% gasoline by volume (M85) (flexible-fuel) |
| | 7) Fuel mixture of 85% ethanol and 15% gasoline by volume (E85) (flexible-fuel) |
| | 8) Fuel mixture of 10% ethanol and 90% gasoline by volume (E10) (flexible-fuel) |
| | 9) Liquefied natural gas (LNG) |
| | 10) Liquefied petroleum gas (LPG) |
| | 11) Fuel mixture of 90% methanol and 10% gasoline by volume (M90) (dedicated) |
| | 12) Fuel mixture of 90% ethanol and 10% gasoline by volume (E90) (dedicated) |
| | 13) Gaseous hydrogen ($GH_2$) |
| | 14) Liquid hydrogen ($LH_2$) |
| Spark-ignition, direct-injection (SIDI) engine vehicles | 15) Conventional gasoline (CG) |
| | 16) Reformulated gasoline (RFG) |
| | 17) California reformulated gasoline (CARFG) |
| | 18) Fuel mixture of 10% ethanol and 90% gasoline by volume (E10) |
| | 19) Fuel mixture of 90% methanol and 10% gasoline by volume (M90) |
| | 20) Fuel mixture of 90% ethanol and 10% gasoline by volume (E90) |
| Compression-ignition, direct-injection (CIDI) engine vehicles | 21) Conventional diesel (CD) |
| | 22) Low-sulfur diesel (LSD) |
| | 23) Dimethyl ether (DME) |
| | 24) Fischer-Tropsch diesel (FTD) |
| | 25) Mixture of 20% biodiesel and 80% diesel by volume (BD20) |
| | 26) E-diesel |

**TABLE 1.2 Vehicle/Fuel Systems Included in GREET 1.7 (Cont'd.)**

| Vehicle Technology | Fuel |
|---|---|
| Grid-independent (GI) spark-ignition (SI) engine hybrid electric vehicles (HEVs) | 27) Conventional gasoline (CG) |
| | 28) Reformulated gasoline (RFG) |
| | 29) California reformulated gasoline (CARFG) |
| | 30) Fuel mixture of 10% ethanol and 90% gasoline by volume (E10) |
| | 31) Compressed natural gas (CNG) |
| | 32) Liquefied natural gas (LNG) |
| | 33) Liquefied petroleum gas (LPG) |
| | 34) Fuel mixture of 90% methanol and 10% gasoline by volume (M90) |
| | 35) Fuel mixture of 90% ethanol and 10% gasoline by volume (E90) |
| | 36) Gaseous hydrogen ($GH_2$) |
| | 37) Liquid hydrogen ($LH_2$) |
| Grid-independent (GI) compression-ignition, direct-injection (CIDI) engine hybrid electric vehicles (HEVs) | 38) Conventional diesel (CD) |
| | 39) Low-sulfur diesel (LSD) |
| | 40) Dimethyl ether (DME) |
| | 41) Fischer-Tropsch diesel (FTD) |
| | 42) Mixture of 20% biodiesel and 80% diesel by volume (BD20) |
| | 43) E-diesel |
| Grid-connected (GC) spark-ignition (SI) engine hybrid electric vehicles (HEVs) | 44) Conventional gasoline (CG) and electricity |
| | 45) Reformulated gasoline (RFG) and electricity |
| | 46) California reformulated gasoline (CARFG) and electricity |
| | 47) Fuel mixture of 10% ethanol and 90% gasoline by volume (E10) and electricity |
| | 48) Compressed natural gas (CNG) and electricity |
| | 49) Liquefied natural gas (LNG) and electricity |
| | 50) Liquefied petroleum gas (LPG) and electricity |
| | 51) Fuel mixture of 90% methanol and 10% gasoline by volume (M90) and electricity |
| | 52) Fuel mixture of 90% ethanol and 10% gasoline by volume (E90) and electricity |
| | 53) Gaseous hydrogen ($GH_2$) and electricity |
| | 54) Liquid hydrogen ($LH_2$) electricity |
| Grid-connected (GC), compression-ignition, direct-injection (CIDI) engine hybrid electric vehicles | 55) Conventional diesel (CD) and electricity |
| | 56) Low-sulfur diesel (LSD) and electricity |
| | 57) Dimethyl ether (DME) and electricity |
| | 58) Fischer-Tropsch diesel (FTD) and electricity |
| | 59) Mixture of 20% biodiesel and 80% diesel by volume (BD20) and electricity |
| | 60) E-diesel and electricity |

**TABLE 1.2 Well-to-Wheels (WTW) Vehicle/Fuel Systems Included in GREET1.7 (Cont'd.)**

| Vehicle Technology | Fuel |
|---|---|
| Electric vehicles (EVs) | 61) Electricity |
| Fuel cell vehicles (FCVs) | 62) Gaseous hydrogen ($GH_2$) |
| | 63) Liquid hydrogen ($LH_2$) |
| | 64) Methanol (MeOH) |
| | 65) Ethanol (EtOH) |
| | 66) Gasoline |
| | 67) California reformulated gasoline (CARFG) |
| | 68) Low-sulfur diesel (LSD) |
| | 69) Compressed natural gas (CNG) |
| | 70) Liquefied natural gas (LNG) |
| | 71) Liquefied petroleum gas (LPG) |
| | 72) Naphtha |

The following sections briefly introduce the 27 individual working sheets in GREET 1.7.

## 1.1 The Overview Sheet

This sheet contains the GREET copyright statement. It presents a brief summary of each worksheet in GREET and is intended to provide brief introduction to the functions of each sheet. It is highly recommended that first-time GREET users read this sheet before proceeding with any GREET calculations.

## 1.2 The Inputs Sheet

This sheet presents key variables for various well-to-pump (WTP) and pump-to-wheels (PTW) scenarios, and specifies key parametric assumptions for GREET simulations. GREETGUI, the front end user interface, interacts mainly with this sheet to set the parameters for the fuel pathways to be simulated in GREET. This sheet serves as a bridge between the GREETGUI program and the GREET spreadsheet model running in the background, when users use the GREETGUI program to run the GREET model.

As explained in the Overview sheet, the cells colored in yellow and green are input cells and represent the key options and parameters for simulating different fuel cycles in GREET. You can edit the yellow and green cells to change the default simulation options or assumptions in these cells. The green cells have probability distribution functions built into them for use with the stochastic simulation feature of the GREET model. With GREET stochastic simulations, stochastic results rather than a point estimate of energy use and emissions can be generated.

The cells without background color have formulas linked to other cells or to time-series (TS) tables in other worksheets of the GREET model.

***You are cautioned against making any changes to cells without background colors, as this can result in broken formula links and failed GREET simulations.***

To change any of the key parameters associated with time-series (lookup) tables, e.g., conventional crude recovery efficiency, you may go to the appropriate time-series worksheet (e.g., *Fuel_Prod_TS* in this case) to change the entry of the corresponding yellow cell immediately above the time-series table.

This sheet is separated into fourteen sections:

1) Selection of key options for simulation.
2) Selection of vehicle types for simulation.
3) Key input parameters for simulating petroleum-based fuels.
4) Key input parameters for simulating natural gas-based fuels. (Key input parameters for feedstock sources [e.g., biomass] other than natural gas (NG) for simulating Fischer-Tropsch Diesel [FTD], dimethyl ether [DME], and methanol [MeOH] are also included in this section.)
5) Key input parameters for simulating hydrogen.
6) Assumptions regarding boil-off effects of liquefied natural gas (LNG) and liquid $H_2$ ($LH_2$).
7) Transportation distance from feedstock production sites to final destinations.
8) Key input parameters for simulating fuel ethanol.
9) Key input parameters for simulating soybean-based biodiesel.
10) Key input parameters for simulating electricity generation.
11) Key input parameters for simulating vehicle operations.
12) Key GREET default assumptions for WTP activities.
13) Fuel economy and emission rates of baseline vehicles.
14) Fuel economy and emission changes by alternative-fueled vehicles (AFVs) and advanced vehicle technologies (AVTs).

## 1.3 The EF_TS Sheet

This sheet presents time-series (TS) tables for emission factors (EFs) (in grams per mmBtu of fuel burned) from fuel combustion technologies applied to stationary sources. Volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides ($NO_x$), particulate matter ≤10 µm in aerodynamic diameter ($PM_{10}$), methane ($CH_4$), and nitrous oxide ($N_2O$) emissions from various combustor types fueled with NG, residual oil, diesel, gasoline, crude oil, liquefied petroleum gas (LPG), coal, biomass, and $H_2$ may change over time, as well as sulfur oxide ($SO_X$) emissions from various combustor types fueled with coal, biomass, crude, and residual oil. Time-series tables for emission factors associated with different WTP activities in this sheet have the same format and functionality of those created in the *Fuel_Prod_TS* sheet (see detailed introduction of the *Fuel_Prod_TS* sheet in section 1.8). Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *EF* sheet (see section 1.4) for emission rate calculations by GREET.

## 1.4 The EF Sheet

This sheet presents emission factors for individual combustion technologies that burn various fuels. GREET uses these emission factors in other sheets to calculate emissions associated with fuel combustion in various WTP stages.

The first section of this sheet lists emission factors for combustion technologies applied to stationary sources. Because emission factors are changed over time for stationary fuel combustion technologies in this section, all the cells have formula links with some other cells or time-series tables in the *EF_TS* sheet (see introduction for the *EF_TS* sheet in section 1.3). Carbon dioxide ($CO_2$) emission factors for all combustion fuels are calculated by using a carbon balance approach. $SO_X$ emission factors for combustion technologies of all fuels, except for coal, biomass, crude and residual oil, are calculated by assuming that all sulfur contained in these process fuels is converted into sulfur dioxide ($SO_2$).

***You are cautioned against making any changes to the cells for $CO_2$ and $SO_X$ emissions, as this can result in broken formula links and failed GREET simulations.***

For those emission factors linked to time-series tables, e.g., VOCs, CO, $NO_x$, $CH_4$, and $N_2O$, you may go to the *EF_TS* sheet to make desired changes to the emission factors in the yellow cells.

The second section contains emission factors for different transportation modes. It includes three tables. The first table lists emission changes of transportation modes powered with alternative fuels relative to those powered with a baseline fuel (such transportation modes include ocean tankers, barges, locomotives, trucks, pipelines, etc.). The second table lists the emission rates for different transportation modes powered with different fuels used for the trips from the product origin to its destination. The third table lists the emission rates for different transportation modes powered with different fuels used for the trips from product destinations back to its origin (back-haul trips).

## 1.5 The Fuel_Specs Sheet

This sheet includes specifications for individual fuels. Fuel specifications of interest to GREET are lower and higher heating values, fuel density, carbon weight ratio, and sulfur weight ratio. While GREET simulations are based on lower heating values for fuels, users could conduct simulations based on higher heating values for fuels. Probability distribution functions are built for most of the fuel specifications, which can be found in the cells with a green background. These fuel specifications are used to estimate energy consumption and emissions, as well as conversions among mass, volume, and energy contents.

This sheet also contains other conversion parameters such as the global warming potentials (GWPs) for individual greenhouse gases (GHGs). These are used in GREET to convert emissions of GHGs into $CO_2$-equivalent emissions. The *Fuel_Specs* sheet also contains the carbon content in VOCs, CO, $CH_4$, and $CO_2$, and the sulfur content in $SO_2$. These are used for carbon emission and $SO_X$ emission calculations throughout the GREET model.

Since sulfur contents in conventional gasoline, conventional diesel, conventional California diesel and non-road diesel are expected to change over time, time-series tables are developed at the bottom of this sheet for the sulfur content of these fuels.

## 1.6 The T&D Sheet

This sheet calculates energy use and emissions for transportation and distribution (T&D) of feedstocks and fuels. The results of this sheet — energy use (in Btu per mmBtu) and emissions (in grams per mmBtu) — are used in other sheets for the calculations associated with the transportation and distribution of different fuels. The calculation logic for transportation of feedstock sources and fuels is shown in Figure 1.1.

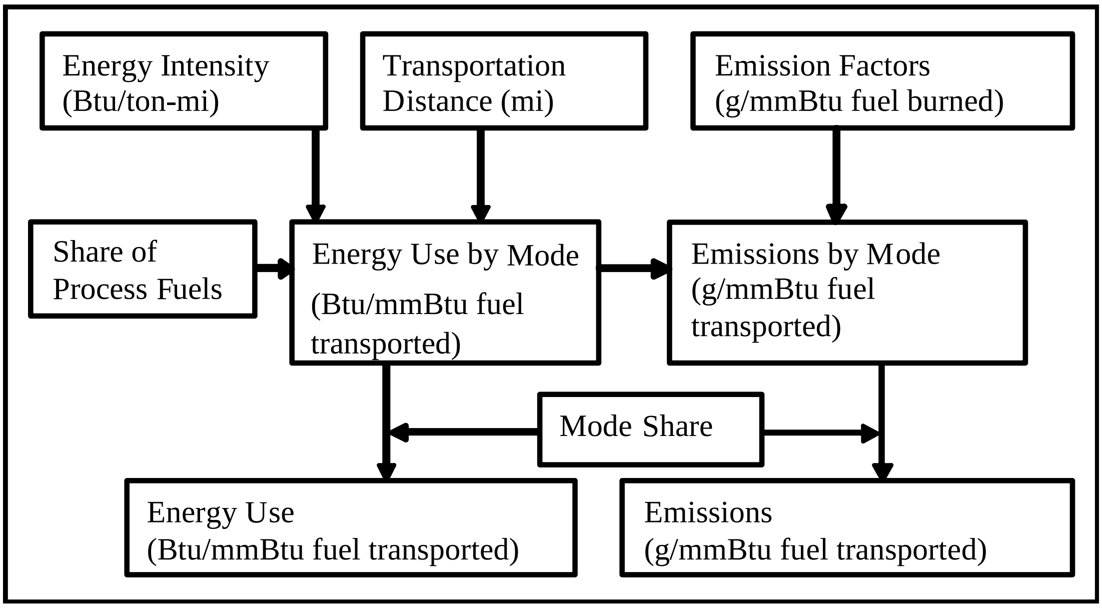



**FIGURE 1.1 Calculation logic for energy use and emissions for activities related to transportation of feedstock sources and fuels**

This worksheet consists of the following ten sections:

1) Cargo payload by transportation mode and by product fuel type.
2) Horsepower requirements for ocean tankers and barges.

3) Shares of power generation technologies fueled with NG for pipeline operation (i.e., turbines and engines).
4) Fuel economy and resultant energy consumption of heavy-duty trucks for transportation activities.
5) Calculation of energy use for ocean tankers and barges.
6) Energy intensity of rail in Btu/ton-mile.
7) Energy intensity of pipeline in Btu/ton-mile by power technology and pipelined product.
8) Energy intensity ratios of different process fuels used for a given transportation mode relative to baseline fuel.
9) Calculation of energy use and emissions associated with transporting feedstocks and fuels.
10) Summary of energy use and emissions associated with transporting feedstocks and fuels. The summarized results here are used elsewhere in GREET.

## 1.7 The Urban_Shares Sheet

In this sheet, a default split of a given facility type between urban and non-urban areas is provided to calculate urban emissions of five criteria air pollutants (VOC, CO, $NO_X$, $SO_X$, and $PM_{10}$) for that facility type in the GREET model. In particular, the shares between urban and non-urban areas are provided for fuel production activities, fuel transportation activities, and vehicle operations.

## 1.8 The Fuel_Prod_TS Sheet

This sheet presents the key assumptions for various fuel production pathways. Since these parameters may change over time, lookup (time-series) tables are developed for each parameter over the period from 1990 to 2020, in five-year intervals.

In general, time-series lookup tables have two cell entries located above them. The cell immediately above the time-series table, which is colored in yellow, contains the value that is interpolated from the time-series table and that represents the value of the parameter corresponding to the year targeted for simulation. The yellow cell above the time-series table also serves as a user input cell.

***If you adjust the yellow cell's value, the entire time-series table may be automatically adjusted by the same percentage, based on the time-series simulation option selected in Section 1.3 of the Inputs sheet.***

Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the *Inputs* sheet.

Cells immediately above the yellow cells, which are colored in green, have built-in probability distributions for stochastic simulations. The GREET model can generate stochastic results rather than point estimates of energy use and emissions. Note that not all parameters have distribution functions established.

The time-series tables are designed with three columns, which include: target year, parameter value, and relative intensity of the parametric value for a given year relative to that for 2010. The relative intensity values are meant to indicate the relative improvement over time for a given parameter.

The TS lookup tables are separated into twenty eight groups:

1) Conventional oil recovery and fuel refining from conventional oil.
2) Oil sands recovery and fuel refining from oil sands.
3) Natural gas recovery, processing, compression, and liquefaction.
4) Natural gas to liquefied petroleum gas and methanol.
5) Natural gas to FT diesel.
6) Natural gas to FT naphtha.
7) Carbon conversion efficiencies in FT plants.
8) Natural gas to dimethyl ether.
9) Natural gas to gaseous hydrogen in central plants.
10) Natural gas to gaseous hydrogen production in central plants for liquid hydrogen as the final product.
11) Gaseous hydrogen production from other feedstocks in central plants.
12) Gaseous hydrogen production from other feedstocks in central plants for liquid hydrogen as the final product.
13) Electricity use for $CO_2$ capture in central $H_2$ plants.
14) Natural gas, ethanol, and methanol to gaseous hydrogen at stations, electrolysis hydrogen at stations, and gaseous hydrogen compression at stations.
15) Natural gas, ethanol, and methanol to gaseous hydrogen at stations, and electrolysis hydrogen at stations for liquid hydrogen as the final product.
16) Hydrogen liquefaction.
17) Shares of gaseous hydrogen production options.
18) Shares of liquid hydrogen production options.
19) Corn and biomass farming.
20) Ethanol production.
21) Shares of ethanol production.
22) Soybeans to biodiesel.
23) Electricity generation efficiencies.
24) Electric generation technology shares in power plants.
25) Electric generation mixes.
26) Soybeans to biodiesel.
27) Uranium recovery, processing, and enrichment.
28) Biomass to methanol, dimethyl ether, and FT diesel.

For any simulation year between within a five-year interval listed in the TS tables, GREET uses a linear interpolation algorithm to calculate the estimate for that particular year.

## 1.9 The Petroleum Sheet

This sheet calculates WTP energy use and emission rates for the following eight petroleum-based fuels:

- Conventional gasoline (CG)
- Reformulated gasoline (RFG)
- California reformulated gasoline (CARFG)
- Conventional diesel (CD)
- Low-sulfur diesel (LSD)
- Liquefied petroleum gas (LPG)
- Crude naphtha
- Residual oil

Although residual oil is not a vehicle fuel, it is included here to calculate the energy use and emission rates associated with producing different transportation fuels and electricity. The feedstock sources for petroleum fuels in GREET include conventional crude oil and oil sands from Canada.

This sheet also presents calculations for methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), and tertiary amyl methyl ether (TAME), which can be used as oxygenates for the Federal RFG and CARFG fuels. Energy use and emission rate calculations for ethanol as oxygenate are performed in a separate sheet designed specifically for ethanol (*EtOH* sheet, section1.13). Based on the oxygenate type and oxygen ($O_2$) content specified in the *Inputs* sheet for Federal RFG and CARFG, this portion of the *Petroleum* sheet calculates the appropriate amount of the selected oxygenate. Energy use and emission rates associated with producing the selected oxygenate for Federal RFG and CARFG are carefully calculated in GREET.

The calculation logic for WTP production-related activities in this sheet and other following sheet is shown in Figure 1.2.

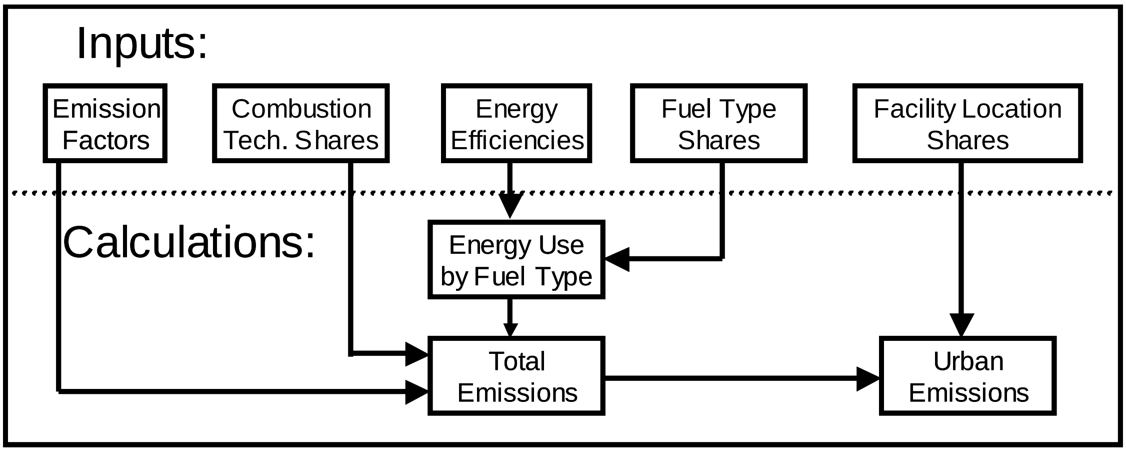



**FIGURE 1.2 Calculation logic for WTP energy use and emissions for activities related to production of feedstock sources and fuels**

This worksheet consists of the following five sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Calculation of energy use and emissions of oxygenate production**
5) **Summary of energy use and emissions.** Other sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.10 The NG Sheet

This sheet presents calculations of energy use and emission rates for NG-based fuels: CNG, liquefied natural gas (LNG), LPG, MeOH, DME, FTD, and Fischer-Tropsch naphtha (FTN). GREET can simulate production of these fuels from North American natural gas, non-North American natural gas, and non-North American flared gas. For CNG and LNG from non-North America sources, GREET assumes that non-North American natural gas and flared gas are converted into LNG for transportation to North America.

Because methanol, FTD, and DME can be produced from biomass, the calculations of energy use and emissions for these three fuels via biomass gasification are also included in this sheet.

Currently, the pathway of methanol production via biomass gasification is just a placeholder in the GREET model, i.e., the model structure is completely in place for this specific fuel pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers for this pathway. Efforts are underway to find reliable data from available sources.

Please note that available data on the pathways of FTD and DME via biomass gasification are very limited. The default data in GREET are based on a study conducted for *The Role of Biomass in America's Energy Future* (for details, see Wu et al.2005). In that study, only one production scenario with electricity co-generation via gas turbine combined cycle (GTCC) was simulated for each of the two fuels. Electricity was no longer a by-product, but a major energy co-product. Two methods — the allocation method and the displacement method — can be applied for electricity credit partition. In this version of GREET, data generated through the RBAEF project were processed for applications with plant designs without electricity export, while the displacement method was applied for the other plant design option (with electricity export).

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET executes calculations of energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other sheets in GREET use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.11 The Hydrogen Sheet

This sheet calculates energy use and emission rates for $H_2$ production pathways. $GH_2$ and $LH_2$ production are simulated separately in this sheet. $H_2$ could be produced either in central plants or at refueling stations.

**In central plants, $H_2$ can be produced from:**

- NG via steam methane reforming (SMR)
- solar energy via photovoltaic
- nuclear energy via thermo-chemical cracking of water using heat from a high-temperature gas-cooled reactor (HTGR)
- nuclear energy via electrolysis using electricity and high-temperature steam from HTGR
- coal via gasification
- biomass via gasification

In the case of $GH_2$ production, $H_2$ will be transported to refueling stations via pipeline and compressed there, while in the case of $LH_2$ production at central plants, $H_2$ will be liquefied in central plants and then transported to refueling stations via rail and trucks and stored at the refueling stations.

**For production at refueling stations, $H_2$ can be produced from**:

- NG via SMR
- grid electricity via electrolysis of water
- EtOH
- MeOH

In the case of $GH_2$ production, $H_2$ is compressed at the refueling stations; while in the case of $LH_2$ production, $H_2$ is liquefied at the refueling stations.

Depending on the type of the electricity generation source selected in the *Inputs* sheet, you may select one of the ten types of electricity generation for $H_2$ production via electrolysis at refueling stations, which include:

- electricity generated from oil power plants
- NG power plants
- coal power plants
- nuclear power plants (light water reactor [LWR] or HTGR can be selected in the *Electric* sheet)
- hydro power plants
- NG combined-cycle turbine power plants
- US generation mix
- North-Eastern US generation mix
- California generation mix
- user defined generation mix

For NG-based $H_2$ production pathways, GREET can simulate $H_2$ production from:

- North American natural gas
- non-North American natural gas
- non-North American flared gas

For the production of $GH_2$ (central or station) and of $LH_2$ (station) from non-North America sources, GREET assumes that non-North American natural gas and flared gas are converted into LNG for transportation to North America, where $GH_2$ and station $LH_2$ are produced.

Currently, the pathway for $H_2$ production from MeOH at refueling stations is a placeholder in GREET, i.e., the model structure is completely in place for this specific fuel pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers. Efforts are underway to find data from available sources.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

Note that the latent energy in each 1 mmBtu of $H_2$ are accounted for in the calculations of solar-to-$H_2$, nuclear-to-$H_2$, and electrolysis-to-$H_2$ pathways within this sheet, but are eventually excluded from the WTP results shown in the *Results* sheet.

## 1.12 The Ag_Inputs Sheet

This sheet calculates production of agricultural chemicals (or agricultural inputs, *Ag_Inputs*), including synthetic fertilizers and pesticides, which are used for the farming of corn, cellulosic biomass, and soybeans. Corn is a feedstock for ethanol; cellulosic biomass is a feedstock for ethanol, methanol, FTD, DME, and $H_2$; and soybeans are a feedstock for biodiesel.

Three fertilizers are simulated in GREET:
- nitrogen (which, in turn, includes ammonia, urea, and ammonium nitrate)
- phosphate
- potash

Pesticides include herbicides and insecticides. This sheet includes calculations for the manufacturing of the chemicals in fertilizers and pesticides. Energy use and emissions for transporting the chemicals from manufacturing plants to farms are calculated in the T&D sheet of GREET (see section 1.9) but they are accounted for in this sheet.

The calculation logic in this sheet is similar to that in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:
1) **Shares of combustion processes for each stage,** which are used for emission calculations.
2) **Calculation of energy use and emissions for individual chemical production processes.** In this section, GREET calculates energy use and emissions for each individual process by considering energy and material requirements, energy efficiency, fuel use by type, fuel use by combustion technology, etc.
3) **Calculation of energy use and emissions for individual chemical products, including production processes and feedstock sources.**
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual chemical WTW calculations.

## 1.13 The EtOH Sheet

This sheet calculates energy use and emission rates for ethanol production from corn, woody biomass, and herbaceous biomass. The following stages are included in this sheet: corn/biomass farming and transportation; corn/biomass ethanol production; and transportation, distribution, and storage of the ethanol fuel. For corn-based ethanol, the sheet includes both wet and dry milling plants. For each corn-based ethanol plant type, energy and emission credits for ethanol co-products (e.g., animal feed) can be estimated by using either the displacement method or the market value method. For ethanol production from woody and herbaceous biomass, the energy and emission credits for the co-generated electricity in cellulosic ethanol plants can be estimated by using either the displacement method or the allocation method.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy and material use, energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.14 The E-D Additives Sheet

This sheet presents energy use and emission rate calculations for additives, which are used to blend ethanol and diesel fuel together (E-diesel or E-D).

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET executes calculations of energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.15 The BD Sheet

This sheet calculates energy use and emission rates associated with producing biodiesel (BD) from soybeans. The sheet includes soybean farming and transportation, soyoil extraction, soyoil transesterification to biodiesel, and biodiesel transportation. Energy use and emission rates are allocated between biodiesel and by-products according to the displacement method.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:

1) **Scenario control and key input parameters.** The values in this section derive primarily from the *Inputs* sheet. Thus, this section is the interactive link between the *Inputs* sheet and this sheet.
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy and material use, energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.16 The Coal Sheet

This sheet calculates the energy use and emission rates for the mining, cleaning, and transportation of coal. The results of this sheet are used in other fuel sheets, in which coal might be used as a process fuel or as a feedstock. For example, in calculating the energy use and emission rates associated with electricity generation in coal-fired power plants, energy use and emission rates associated with coal mining, cleaning, and transportation are added into electricity generated from coal-fired power plants. These calculations are also used in the *Hydrogen* sheet for calculating energy use and emission rates for the production of $H_2$ from coal via gasification.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following three sections:

1) **Shares of combustion processes for each stage,** which are used for emission calculations.
2) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.

3) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for each individual vehicle/fuel WTW calculations.

## 1.17 The Uranium Sheet

This sheet calculates the energy use and emission rates associated with
- uranium ore mining
- uranium ore transportation
- uranium fuel enrichment
- uranium conversion
- fabrication and waste storage at uranium processing plants and enrichment plants
- uranium fuel transportation

The results of this sheet are used in the *Electric* sheet for calculating the energy use and emission rates associated with the electricity produced in nuclear electric power plants using the LWR or the HTGR technologies. Even though nuclear power plants have zero operational energy use and emission rates, the upstream processing and the transportation of uranium consume energy and generate emissions. The results of this sheet are also used in the *Hydrogen* sheet for calculating energy use and emission rates associated with the production of $H_2$ from nuclear energy via thermo-chemical cracking of water using heat from HTGR.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following four sections:
1) **Scenario control and key input parameters.**
2) **Shares of combustion processes for each stage,** which are used for emission calculations.
3) **Calculation of energy use and emissions for individual stages.** In this section, GREET executes calculations of energy use and emissions for each individual stage by considering energy and material use, energy efficiency, fuel use by type, fuel use by combustion technology, etc.
4) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for individual vehicle/fuel WTW calculations.

## 1.18 The LF_Gas Sheet

This sheet presents energy use and emission rate calculations for producing methanol from landfill gases (*LF_Gas*). GREET assumes that, without methanol production, landfill gases would otherwise be flared. Flaring the gases generates a significant amount of emissions. The mission rates offset by producing methanol from landfill gases are taken into account as emission credits. However, the emissions associated with methanol combustion are taken into account during the vehicle operation stage.

The calculation logic used in this sheet is similar to that used in the *Petroleum* sheet (see Figure 1.2).

This worksheet consists of the following three sections:

1) Shares of combustion processes for each stage, which are used for emission calculations.
2) **Calculation of energy use and emissions for individual stages.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
3) **Summary of energy use and emissions.** Other GREET sheets use the summary results from this sheet for each individual vehicle/fuel WTW calculations.

### 1.19 The Electric Sheet

This sheet calculates energy use and emission rates associated with the generation of electricity, which is used for production of transportation fuels and for the operation of electric vehicles and grid-connected hybrid electric vehicles (HEVs). In this sheet, GREET can either calculate the emission rates for electric power plants based on the combustion emission factors incorporated in the model, or take emission factors directly from user input. Energy use and emission rates during processing and transportation of power plant fuels, as well as during power plant electricity generation, are all accounted for in the GREET model.

The results in this sheet are shown as Btu or g/mmBtu of available electricity. This reflects electricity loss during transmission and distribution of electricity from the power plant(s) to the point of end use.

This sheet simulates more than ten types of electricity generation, including electricity generated from

- oil power plants
- NG power plants
- coal power plants
- nuclear power plants (LWR or HTGR)
- hydro power plants
- NG combined-cycle turbine power plants
- US generation mix
- North-eastern US generation mix
- California generation mix
- user defined generation mix
- others

Since emission factors of various power plant boilers are expected to change over time, time-series tables are presented at the bottom of this sheet for criteria air pollutants (VOC, CO, $NO_X$, $PM_{10}$ and $SO_X$) in g/kWh, which are derived from the U.S. Environmental Protection Agency's (EPA's) electric power plant emission database. The cell immediately above the time-series table, which is colored in yellow, is interpolated from the time-series table and represents the value of the parameter corresponding to the year targeted for simulation. The yellow cell above the time-series table also serves as a user input cell.

***If you adjust the yellow cell's value, the entire time-series table may be automatically adjusted by the same percentage, depending on the time-series simulation option selected in Section 1.3 of the Inputs sheet. Changes made to the yellow cells immediately above the time-series tables are automatically linked to Section 4 of this worksheet.***

Those cells immediately above the yellow cells, which are colored in green, have probability distribution functions built into them for use with stochastic simulations in GREET.

The calculation logic used in this sheet is similar to that used in the Petroleum sheet (see Figure 1.2).

This worksheet consists of the following eight sections:

1) **Scenario control and key input parameters.** Some values in this section derive from the *Inputs* sheet. Thus, this section also acts as the interaction between the *Inputs* sheet and this sheet.
2) **Electricity generation mix, power plant fuel combustion technology shares, and power plant conversion efficiencies.**
3) **Electricity transmission and distribution losses.**
4) **Calculation of energy use and emissions of electricity generation in power plants.** In this section, GREET calculates energy use and emissions for each individual stage by considering energy efficiency, fuel use by type, fuel use by combustion technology, etc.
5) **Energy use and emissions of electric generation for electricity available at wall-outlet in Btu or grams per kWh.**
6) **Energy use and emissions of electric generation for electricity available at wall-outlet in Btu or grams per mmBtu of electricity.**
7) **Fuel-cycle energy use and emissions for electricity available at wall-outlet in Btu or grams per mmBtu of electricity.** The results here are used by other sheets of GREET for WTW calculations.
8) **Time-series lookup tables for power plant emission factors in g/kWh.**

## 1.20 The Car_LDT1_TS Sheet

In GREET, energy use and emissions of vehicle operations for a given vehicle/fuel option are calculated with fuel economy and emissions of baseline vehicles (gasoline and diesel vehicles) and relative changes in fuel economy and emissions for the given vehicle/fuel option. The Car_LDT1_TS sheet presents parametric assumptions for calculations for passenger cars and light-duty truck 1 (LDT1).

This sheet consists of two sections. The first section contains time-series tables of fuel economy and emission rates for baseline vehicles fueled with gasoline or diesel. The emission factors for exhausted VOC, evaporative VOC, CO, $NO_X$, exhausted $PM_{10}$, tire and brake wear $PM_{10}$, $CH_4$ and $N_2O$ are included in each time-series table in this sheet. Next to each TS lookup table, a similar table is set for each baseline vehicle technology. The cells in these tables, which are colored in green, have probability distribution functions built into them for stochastic simulations for each five-year interval.

The second section contains time-series tables for the changes in fuel economy and emission rates of alternative fuel vehicles (AFVs) and advanced vehicle technologies (AVTs) relative to the baseline gasoline or diesel vehicles. While fuel economy and emission rates are different between passenger cars and LDTs for baseline technologies, the relative changes for AFVs and AVTs are assumed in the GREET the same between cars and LDT1.

The time-series tables in this sheet have the same format and functionality as those created in the *EF_TS* and *Fuel_Prod_TS* sheets, which are discussed above in sections 1.3 and 1.8, respectively.

***Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the Inputs sheet for calculations of energy use and emission rates associated with vehicle operations.***

Those cells next to look-up (time-series) tables (for baseline vehicles) or immediately above the yellow cells (for AFVs and AVTs), which are colored in green, have probability distribution functions built into them for stochastic simulations. The GREET model can generate stochastic results rather than a point estimate of energy use and emission rates.

Note that the values in the TS tables of this sheet are based on each five-model-year instead of calendar-year (i.e., target year). Because emission rates of vehicle operations will deteriorate over time, the data of the lifetime mileage midpoint for a typical model-year vehicle should be applied for simulation. The GREET model was designed to do so. On average, half lifetime of a light-duty vehicle is about five years in the U.S. That means in GREET, for example, simulation for calendar year 2010 uses the values for model-year 2005 vehicles.

## 1.21 The LDT2_TS Sheet

This worksheet is similar to the *CAR_LDT1_TS* worksheet in format and functionality. However, the time-series tables of fuel economy and emission rates/changes associated with vehicle operations are presented here for the light-duty truck 2 (LDT2).

***Changes made to the yellow cells immediately above the time-series tables in this worksheet are automatically linked to the Inputs sheet for calculations of energy use and emissions due to vehicle operations.***

Those cells next to look-up (time-series) tables (for baseline vehicles) or immediately above the yellow cells (for alternative-fueled vehicles and advanced vehicle technologies), which are colored in green, have probability distribution functions built into them for stochastic simulations. The GREET model can generate stochastic results rather than a point estimate of energy use and emission rates.

Note that the values in the TS tables of this sheet are based on each five-model-year instead of calendar-year (i.e., target year). Because emission rates of vehicle operations will deteriorate over time, the data of the lifetime mileage midpoint for a typical model-year vehicle should be applied for simulation. The GREET model was designed to do so. On average, half lifetime of a light-duty vehicle is about 5 years in the U.S. That means in GREET, for example, simulation for calendar year 2010 uses the values for model-year 2005 vehicles.

## 1.22 The Vehicles Sheet

The *Vehicles* sheet calculates energy use and emission rates associated with vehicle operations. This sheet consists of three sections.

The first section (*Scenario Control*) includes key inputs (from *Inputs* sheet) for

- methanol and ethanol flexible-fuel vehicles
- vehicles with low-level ethanol blended in gasoline
- dedicated methanol and ethanol vehicles
- others

You can specify the content of methanol or ethanol in the fuel blends. For Fischer-Tropsch diesel and biodiesel blended with diesel, you can specify the content of Fischer-Tropsch diesel or biodiesel in the fuel blends. For ethanol blended with diesel, you can specify the content of ethanol and additives in the fuel blends. Furthermore, you can specify the market share of RFG (out of RFG and CG) or the market share of LSD (out of LSD and CD) for these alternative fuel blends. The split of vehicle miles traveled (VMT) using grid electricity and VMT using onboard internal combustion engines (for grid-connected HEVs) is also presented in this section.

The second section of the *Vehicles* sheet (*Vehicle Fuel Economy and Emission Changes*) presents fuel economy and emission changes associated with alternative-fueled vehicles and advanced vehicle technologies relative to the baseline gasoline or diesel vehicles. These fuel economy and emission changes may change over time, and are linked to time-series tables, which are presented in the *Cars_LDT1_TS* and *LDT2_TS* sheets.

The third section (*Per-Mile Fuel Consumption and Emissions*) in the *Vehicles* sheet calculates energy use and emission rates associated with vehicle operations for individual vehicle types. The fuel economy and emission rates of baseline gasoline/diesel vehicles, alternative-fueled vehicles (AFVs) and advanced vehicle technologies (AVTs) are calculated in this section.

## 1.23 The Results Sheet

This sheet presents results for vehicle/fuel options included in the GREET model. The sheet consists of three sections.

1) The **Well-to-Pump Energy Use and Emissions** section presents energy and emission results from wells to refueling station pumps (WTP, in Btu or grams per mmBtu of fuel available at fuel pumps) for each transportation fuel included in GREET.
2) The **Well-to-Wheels Energy Use and Emissions** section calculates fuel-cycle (well-to-wheels, WTW) energy use and emission rates for all vehicle/fuel options included in GREET. For each vehicle/fuel option, energy use and emission rates are separated into three stages: feedstock (including feedstock recovery, transportation, and storage), fuel (including fuel production, transportation, storage, and distribution), and vehicle operation. Shares of energy use and emission rates by each of the three stages are also presented in this section. This section also calculates both urban emissions (emissions occurring in urban areas) and total emissions (emissions occurring everywhere) for the five criteria pollutants.
3) The **Well-to-Wheels Energy and Emission Changes** section calculates changes in fuel-cycle energy use and emission rates for each alternative-fueled vehicle or advanced vehicle technology. These changes are calculated against gasoline vehicles fueled with gasoline (CG and/or RFG).

You can generate stochastic results for WTP results, WTW results, and WTW relative changes in the forecast cells defined in this sheet, which are colored in blue.

## 1.24 The Graphs Sheet

This sheet presents bar charts for the shares of energy use and emission rates of feedstock, fuel, and vehicle operations, for each simulated fuel/vehicle type. Furthermore, it shows energy use and emissions changes by individual vehicle technologies relative to the baseline gasoline vehicles powered by conventional gasoline and/or reformulated gasoline.

The following paragraphs describe worksheets applicable only in the stochastic simulation scenario

## 1.25 The Dist_Specs Sheet

This sheet contains the detailed specifications of those input parameters built with distribution functions. The following is the order of parameters presented in the sheet:

| | |
|---|---|
| Column A: | name of the worksheet containing the input cell with a distribution function |
| Column B: | cell address in the worksheet for the input parameter |
| Column C: | type of probability distribution function used for the input parameter |
| Columns D-I: | user-input and/or GREET-default key parameters for the selected distribution function |
| Columns J-O: | GREET-estimated key parameters for the selected distribution function for use in stochastic simulations |
| Columns P-U: | other miscellaneous parameters for the selected distribution function |

***All the contents in this sheet are automatically generated by the GREET model. You are cautioned against making any changes to this sheet, as this can result in failed stochastic simulations or incorrect outputs.***

## 1.26 The Forecast_Specs Sheet

This sheet contains the detailed information of defined forecast items for a particular stochastic simulation run. The following is the order of information in the sheet:

| | |
|---|---|
| Column A: | name of the worksheet containing the forecast item |
| Column B: | cell address of the forecast item in the worksheet |
| Column C: | name of the forecast item |

***All the contents in this sheet are automatically generated by the GREET model. You are cautioned against making any changes to this sheet, as this can result in failed stochastic simulations or incorrect outputs.***

## 1.27 The Forecast_Deleted Sheet

This sheet contains the list of the forecast items that were deleted, if any, as specified by the user. The following is the order of information in the sheet:

| | |
|---|---|
| Column A: | name of the worksheet containing the deleted forecast item |
| Column B: | cell address of the deleted forecast item in the worksheet |
| Column C: | name of the deleted forecast item |

***All the contents in this sheet are automatically generated by the GREET model. You are cautioned against making any changes to this sheet, as this can result in failed stochastic simulations or incorrect outputs.***

# 2. GREETGUI User Guide

## 2.1 Introduction

GREETGUI enables the analysis of vehicle fuel-cycles, commonly called well-to-wheels (WTW) analysis, for various fuel/vehicle systems. Based on your input, GREETGUI (1) conducts simulation studies on energy use and emissions associated with production and distribution activities of different transportation fuels, commonly called the well-to-pump (WTP) activities, and (2) analyzes the energy use and emissions associated with vehicle operation for advanced vehicle technologies, commonly called pump-to-wheels (PTW) activities.

For a given transportation fuel/vehicle technology combination, GREETGUI calculates the fuel-cycle energy consumption, greenhouse gas (GHG) emissions and emissions of five criteria pollutants: VOCs, CO, $NO_X$, $SO_X$ and $PM_{10}$.

The GREETGUI program, developed using Microsoft® Visual Basic 6.0, works as follows. Based on user input entered through option buttons, check boxes, and input text boxes, GREETGUI:

1. Communicates the input into an underlying Excel spreadsheet model (GREET),
2. Runs the model in the background, and
3. Displays results in the form of tables in another Excel output file generated by the program.

GREETGUI also generates a second Excel file, which records all inputs during a particular GREETGUI session.

This section describes the system requirements to install and run the GREETGUI simulation program and provides instructions for using the program.

Throughout this document, please note the distinction between GREET, which is the hidden spreadsheet model running in the background and GREETGUI, which is the graphical user interface (GUI) between you and the underlying GREET model.

The setup program installs the GREETGUI program as well as the underlying GREET spreadsheet model in a common folder. The GREET model is an Excel spreadsheet file marked with the Hidden and Read-Only attributes. Figure 2.1 shows the interactive phases of a typical GREETGUI session.

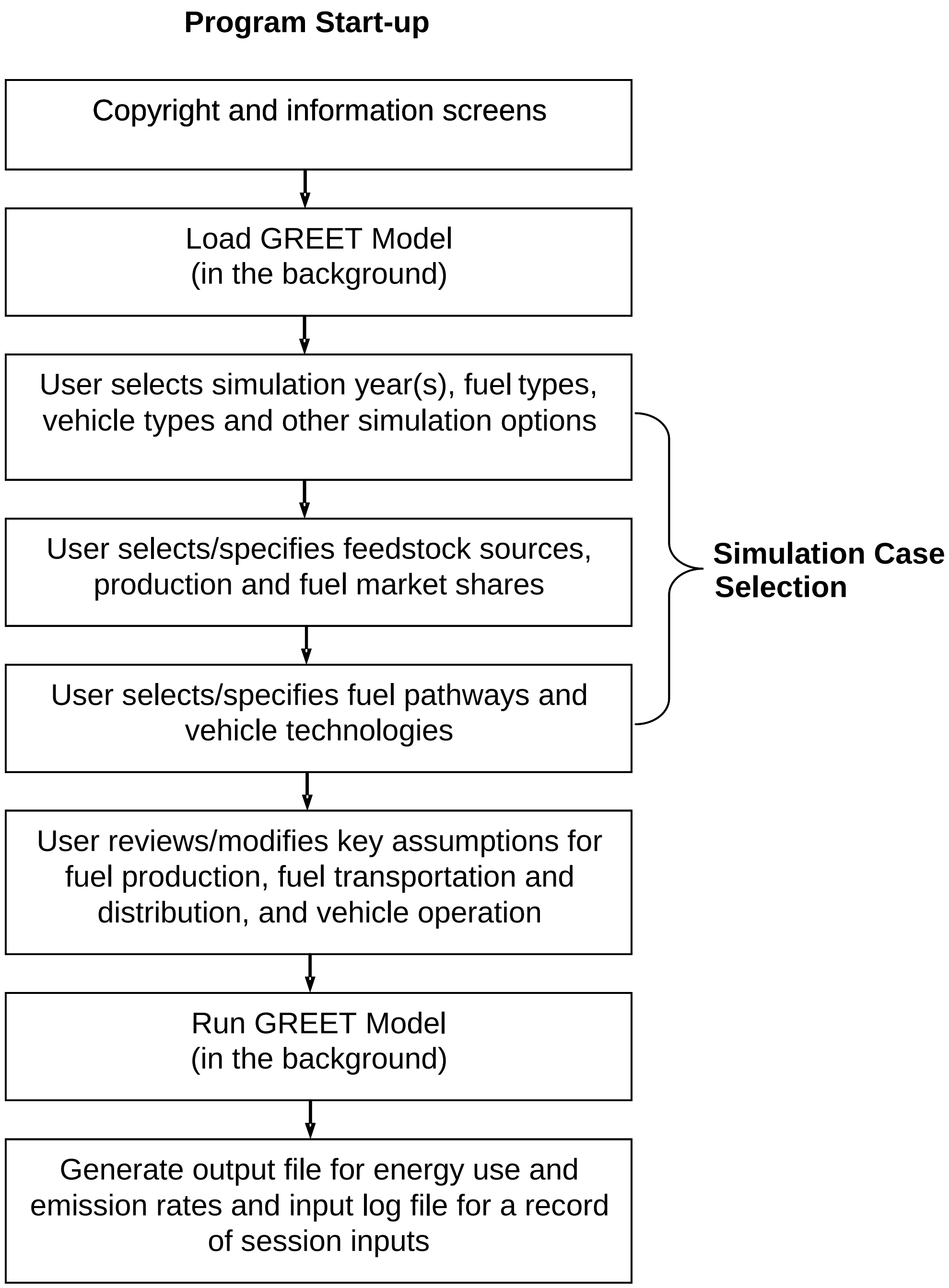



**FIGURE 2.1 Interactive phases in a typical GREETGUI session**

## 2.2 System Requirements for GREETGUI

GREETGUI runs on IBM®-compatible PCs running the following software:

- Microsoft® Windows 2000, Windows Millennium Edition (ME), Windows NT, or Windows XP
- Microsoft® Excel 2000 or higher — **Excel 97 and earlier versions are not compatible with the GREETGUI program**
- Microsoft® Word or Adobe® Acrobat Reader (to view the operating file)

*Minimum* hardware requirements include:

- 166 MHz processor
- 128 MB RAM
- 30 MB free hard drive space

*Recommended* hardware profile:

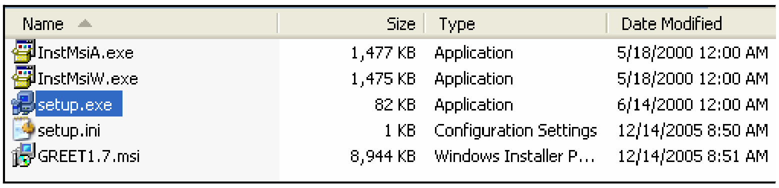
- 400 MHz or higher processor
- 256 MB RAM
- 100 MB free hard disk space.

## 2.3 Installing GREETGUI

Please close all other applications before attempting to install GREETGUI. You may specify the installation drive letter and a folder name or accept the default drive and folder name assigned by the installation program.

To install GREETGUI:

1. Double-click the “setup.exe” application file in the GREETGUI installation package.



| Name | Size | Type | Date Modified |
|---|---|---|---|
| InstMsiA.exe | 1,477 KB | Application | 5/18/2000 12:00 AM |
| InstMsiW.exe | 1,475 KB | Application | 5/18/2000 12:00 AM |
| setup.exe | 82 KB | Application | 6/14/2000 12:00 AM |
| setup.ini | 1 KB | Configuration Settings | 12/14/2005 8:50 AM |
| GREET1.7.msi | 8,944 KB | Windows Installer P... | 12/14/2005 8:51 AM |

2. Follow the on-screen instructions.
3. If prompted to do so, restart the computer to allow the installation process to fully complete.

The installation program creates a shortcut to the GREETGUI program on the desktop.

## 2.4 Using GREETGUI

### 2.4.1. Starting GREETGUI

To run the GREETGUI program:

1. Double-click the program icon.


2. If you are running GREETGUI for the first time, a message box will advise you to open and read a Readme.doc file before using GREETGUI (Figure 2.2). This requires Microsoft Word.

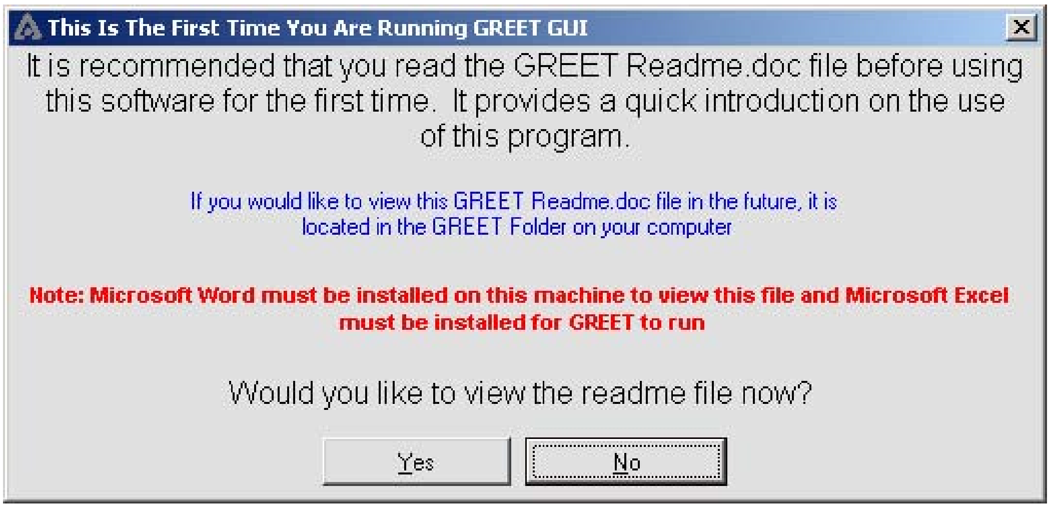



**FIGURE 2.2 First time screen**

The GREETGUI program will also advise you of the location of the Readme.doc file for future access (Figure 2.3).

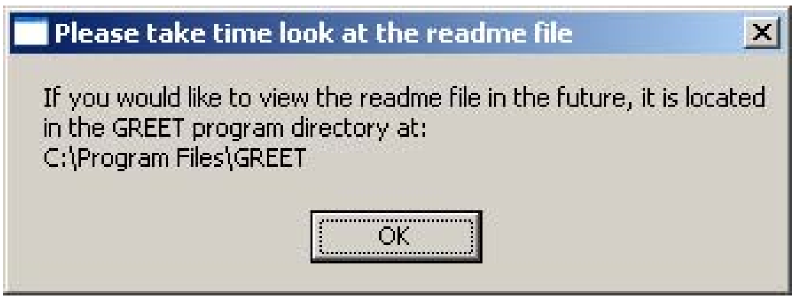



**FIGURE 2.3 Location of GREETGUI readme file**

3. Next, a window opens to display information about the program (Figure 2.4). You may click the **OK** button to continue, or click the **About** button to view the GREETGUI version information.

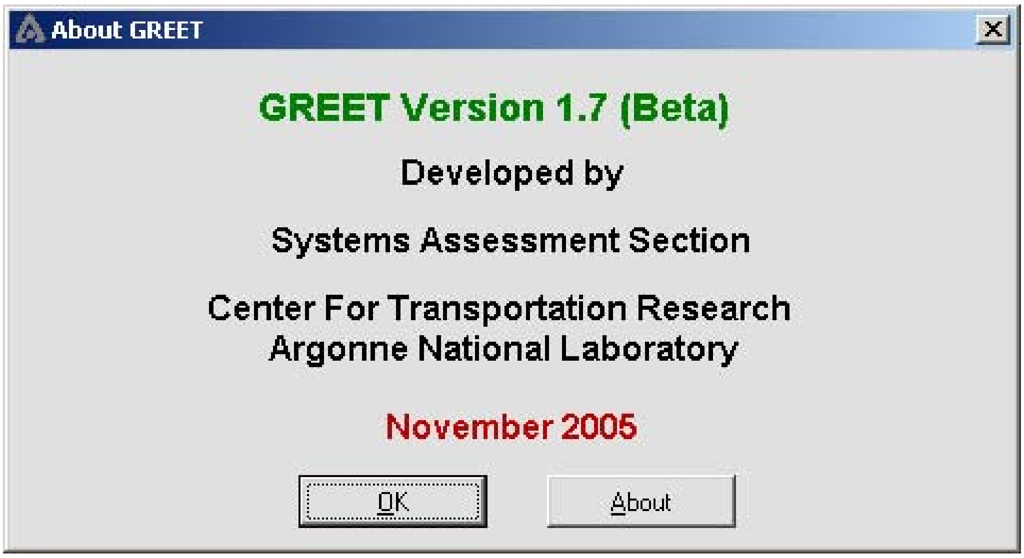



**FIGURE 2.4 GREET version information**

4. A warning window appears, requesting you to close all open Excel files before proceeding with the GREETGUI session (Figure 2.5).

5. Close any open Excel files before clicking the **OK** button to continue with the initiated session; otherwise all open Excel files will be forced to terminate by GREETGUI without saving.

   You must close Excel files for GREETGUI to run properly because GREETGUI manipulates many of the Excel features in the background, which may affect or be affected by the execution of other open Excel files. All Excel files will be terminated without saving if you respond to the warning message by clicking **OK**. Alternatively, you can click the **Cancel** button to quit the GREETGUI Program and keep all loaded Excel files open.


**FIGURE 2.5 Warning message to close all open Excel files**

If you click **OK** in the warning window, GREETGUI will load the GREET spreadsheet model in the background.

6. Next, a Copyright notification screen opens to display the GREETGUI software license terms and conditions (Figure 2.6). Scroll through the Copyright window and read the whole copyright statement before continuing with the GREETGUI software. If you agree to the stated terms and conditions, you can proceed with the initiated GREETGUI session; otherwise, you must exit the GREETGUI program by clicking the **Exit** button.

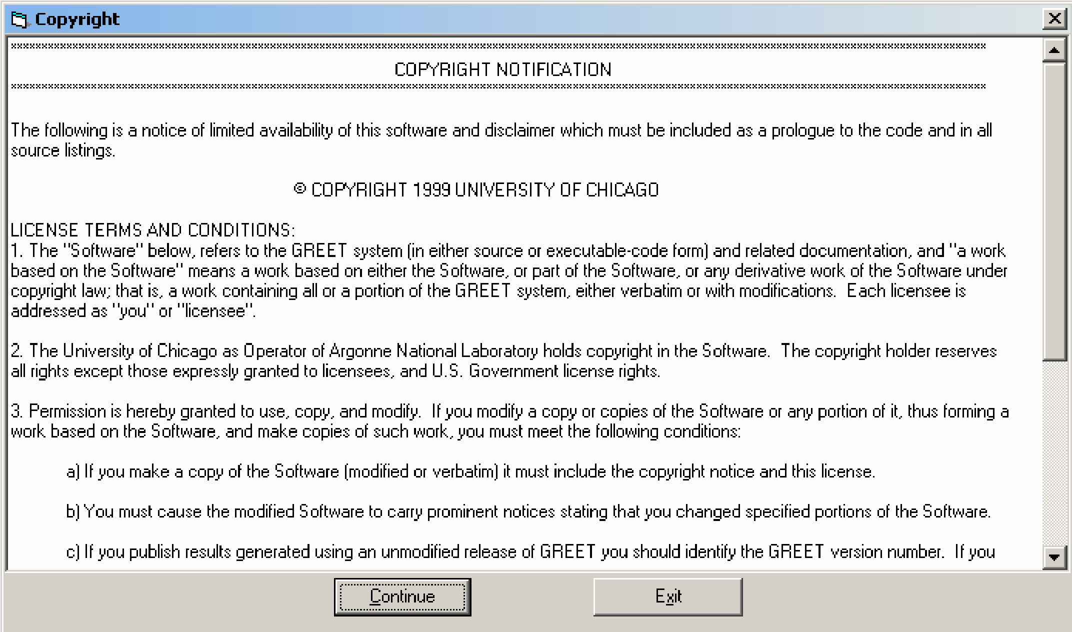



**FIGURE 2.6 Copyright screen**

7. A window with animated graphics displays as GREETGUI initializes (Figure 2.7).


**FIGURE 2.7 Typical background activity screen**

### 2.4.2 Beginning a GREETGUI Session

1. After GREETGUI initializes, the main program window appears, prompting you to Create New Session, Open Existing Session or Exit GREETGUI (Figure 2.8).

   To start a new session, click **New Session**.

   To work on a previously saved session, click **Open Existing Session**.

   To exit the GREETGUI program, click **Exit**.


**FIGURE 2.8 GREETGUI program main screen**

2. If you elect to create a new session, a dialogue box prompts you for a new session name (see Figure 2.9). You may type in a file name for the session or accept the default name "Session.xls," then click the **Save** button.

   GREETGUI appends "Out" to a given session name, e.g., "SessionOut.xls," to create an output file name. Similarly, GREETGUI appends "In" to a given session name, e.g., "SessionIn.xls," to create an input file name (Figure 2.9).

   The output file includes the output results of a completed session, while the input file includes all the market shares, pathways selections, and key assumptions entered during the completed session.

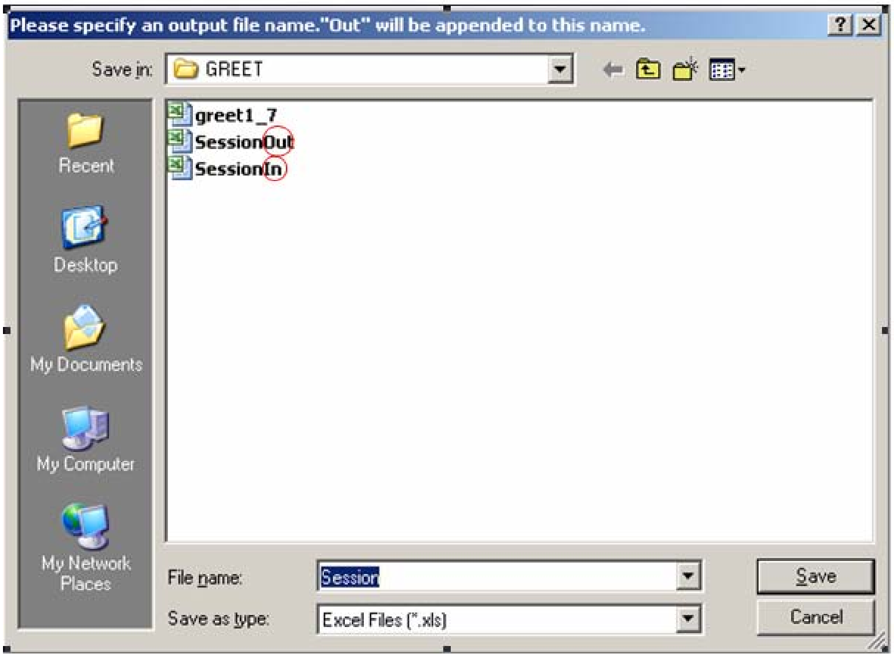



**FIGURE 2.9 File naming in a new GREETGUI session**

3. If you elect to open a previously saved session by clicking the **Open Existing Session** button, GREETGUI displays a list of all previously saved sessions in the GREETGUI folder (Figure 2.10).

   You may highlight a saved session from the displayed list, and click the **Open** button to load that session. You will be warned that leaving the old name of the opened session unchanged would overwrite the results previously stored in that session name.

   Alternatively, you may continue the opened session with a new name, by specifying a different name for the opened session, thus leaving the old results of the opened session unchanged. As mentioned above, GREETGUI appends "Out" to a given session name, e.g., "SessionOut.xls," to create an output file name. Similarly, GREETGUI appends "In" to a given session name, e.g., "SessionIn.xls," to create an input file name.

4. Next, a "Scenario and Fuel Pathway Selections" window opens (Figure 2.11). You may select one or more years to simulate. You must select the vehicle type and the fuel pathways options for one or more of the feedstock and fuel production scenarios, and then click the **Continue** button.

   You may also select the option for a stochastic simulation in GREET. A stochastic simulation tool has been built in the GREET model to address the uncertainties. For information about using GREETGUI to configure the GREET model for stochastic simulations, please see section 2.4.5, "Using GREET for Stochastic Simulation."

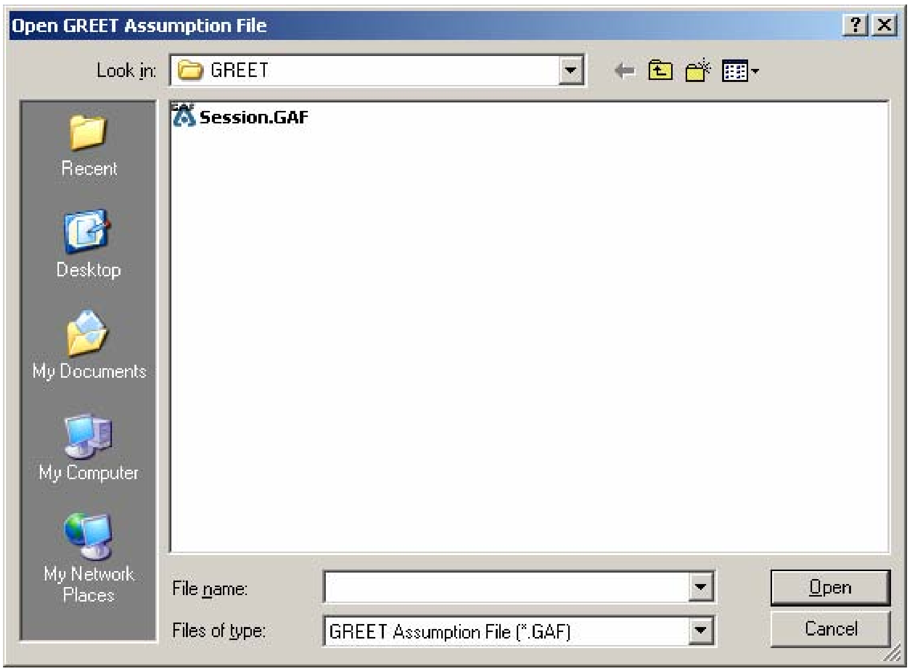



**FIGURE 2.10 Opening a previously saved GREETGUI session**

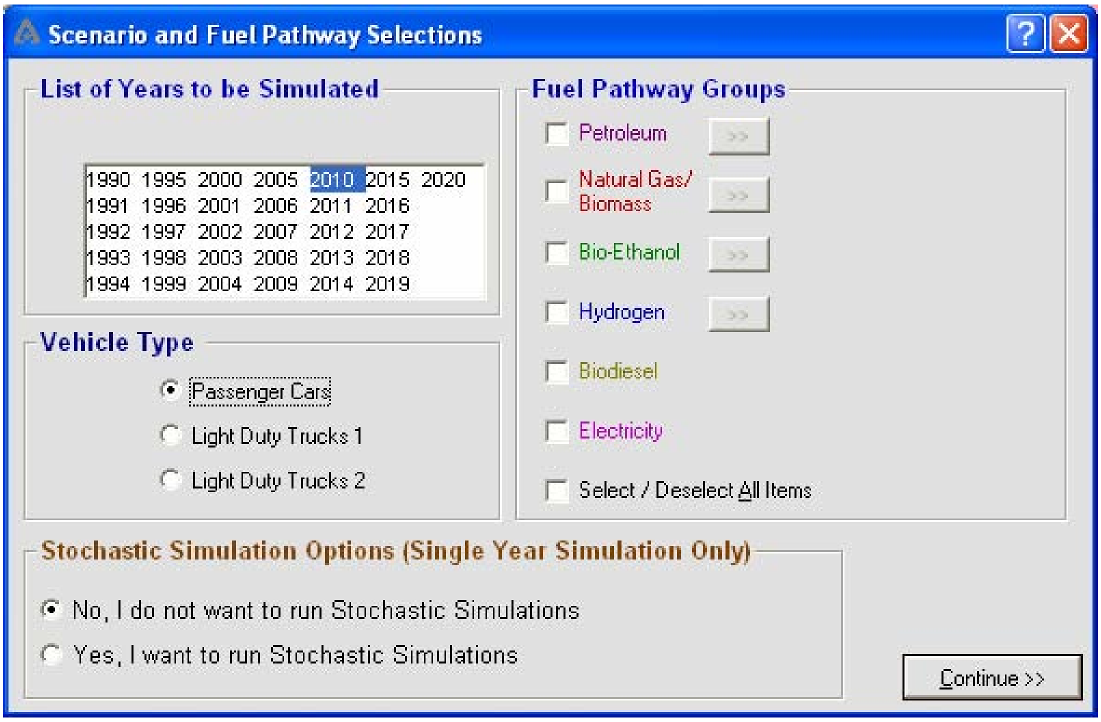



**FIGURE 2.11 Selection of scenarios and fuel pathways**

**Tip:**
GREETGUI provides Help topics and Tooltips to assist with understanding the options and abbreviations in each screen. You may move the mouse cursor over any button or selection in the displayed window to view the tip associated with the selection. You may also click the question mark at the top right corner of the window as shown in Figure 2.11, drag the mouse cursor over any button or selection, and click there to view the available help text associated with that selection. Alternatively, you may click on the selection and then press the F1 key to view the help associated with that selection.

### 2.4.3 Specifying Shares and Technology Options

1. The first of the three main interactive phases of a program session begins with specifying market shares of the selected fuel types. A new window named "Market Shares Options" opens as shown in Figure 2.12.

   This window includes the feedstock and fuel types selected in the window shown in Figure 2.11. For any of the market shares listed, you may select (a) the GREET Default option, (b) the Linear Interpolation option, or (c) the User Specify option.

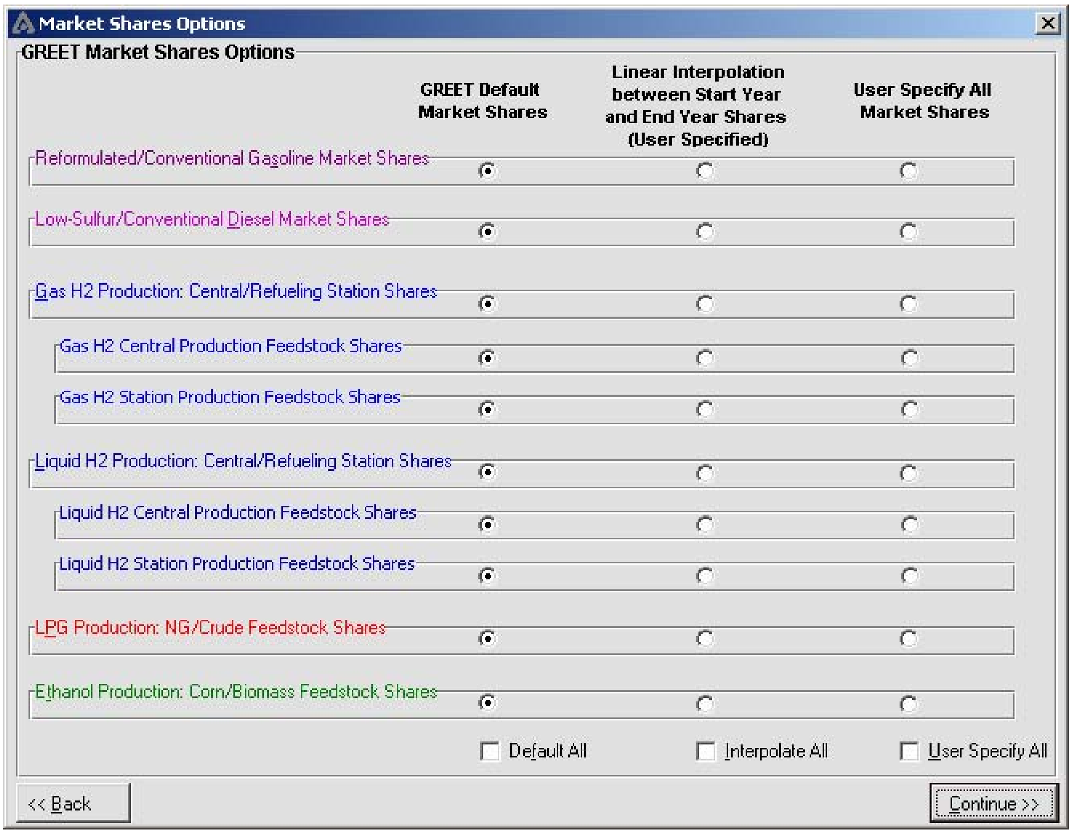



**FIGURE 2.12 User options for market shares specifications**

Note that the GREET spreadsheet model, running in the background, is currently designed to simulate different fuel production pathways scenarios based on estimates in lookup tables for the range of years from 1990 to 2020, arranged in five-year intervals, e.g., 1990, 1995, 2000, etc. (Figure 2.13). Estimates for simulation years that are not divisible by five are calculated from simple interpolation between the estimates immediately surrounding them in the GREET lookup tables. All simulation years beyond 2020 (the last available year in GREET lookup tables) are assumed to have the same estimates for those of 2020 in the lookup tables.

50%

| 5-year period | Share of RFG |
|---|---|
| 1990 | 0% |
| 1995 | 15% |
| 2000 | 30% |
| 2005 | 35% |
| **2010** | **50%** |
| 2015 | 65% |
| 2020 | 100% |

100%

| 5-year period | Share of Low Sulfur Diesel |
|---|---|
| 1990 | 0% |
| 1995 | 0% |
| 2000 | 0% |
| 2005 | 0% |
| **2010** | **100%** |
| 2015 | 100% |
| 2020 | 100% |

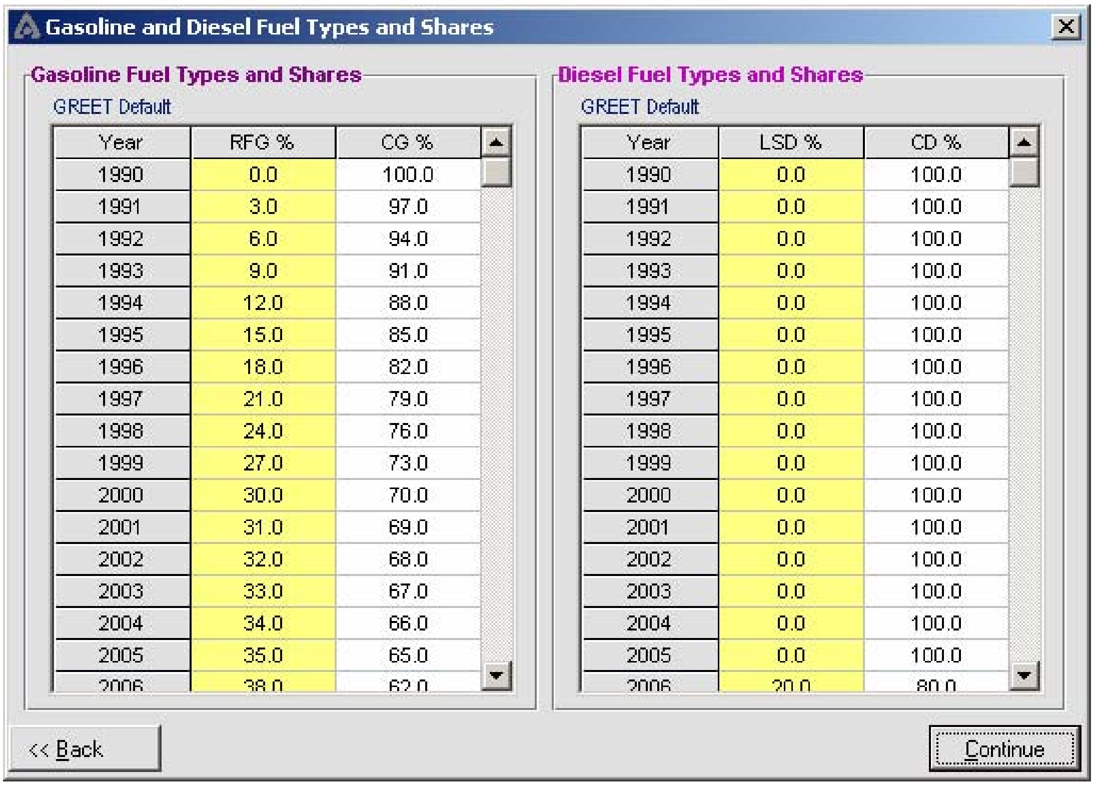
**FIGURE 2.13 Examples of market share lookup tables in GREET**

The **GREET Default** option allows you to view the default market share values in the subsequent windows, but without being able to modify or change them.

The **Linear Interpolation** option allows you to specify market shares for the first and last year of a selected simulation period, and performs simple linear interpolation for all simulation years in between. Therefore, the linear interpolation option is available only if the number of years selected for simulation is three or more.

The **User Specify** option allows you to modify and change the market shares for any of the simulation years as desired. Select the desired market share specification option for each of the shown feedstock and fuel types, and then click the **Continue** button to view the fuel market shares for the selected simulation years.

2. Next, depending on how many feedstock and fuel types are simulated, one or more windows will appear successively, allowing you to review and/or modify the market shares of the selected feedstock and fuel types for all simulation years (see Figure 2.14). You may only edit cells that have a yellow background. All white cells are automatically calculated as the balance of the specified market shares for all simulation years. Click **Continue** to set the market share values for all feedstock and fuel types.




| Year | RFG % | CG % |
|---|---|---|
| 1990 | 0.0 | 100.0 |
| 1991 | 3.0 | 97.0 |
| 1992 | 6.0 | 94.0 |
| 1993 | 9.0 | 91.0 |
| 1994 | 12.0 | 88.0 |
| 1995 | 15.0 | 85.0 |
| 1996 | 18.0 | 82.0 |
| 1997 | 21.0 | 79.0 |
| 1998 | 24.0 | 76.0 |
| 1999 | 27.0 | 73.0 |
| 2000 | 30.0 | 70.0 |
| 2001 | 31.0 | 69.0 |
| 2002 | 32.0 | 68.0 |
| 2003 | 33.0 | 67.0 |
| 2004 | 34.0 | 66.0 |
| 2005 | 35.0 | 65.0 |
| 2006 | 38.0 | 62.0 |

| Year | LSD % | CD % |
|---|---|---|
| 1990 | 0.0 | 100.0 |
| 1991 | 0.0 | 100.0 |
| 1992 | 0.0 | 100.0 |
| 1993 | 0.0 | 100.0 |
| 1994 | 0.0 | 100.0 |
| 1995 | 0.0 | 100.0 |
| 1996 | 0.0 | 100.0 |
| 1997 | 0.0 | 100.0 |
| 1998 | 0.0 | 100.0 |
| 1999 | 0.0 | 100.0 |
| 2000 | 0.0 | 100.0 |
| 2001 | 0.0 | 100.0 |
| 2002 | 0.0 | 100.0 |
| 2003 | 0.0 | 100.0 |
| 2004 | 0.0 | 100.0 |
| 2005 | 0.0 | 100.0 |
| 2006 | 20.0 | 80.0 |

**FIGURE 2.14 Example of market shares screen**

3. The second phase starts with selecting/specifying technology options and estimates associated with the production pathway scenarios of the selected fuels. In this phase, GREETGUI presents you with the estimates of the simulation year closest to 2010, since the GREET model has its best estimates for the year 2010. All other years' estimates are made relative to the estimate of 2010. The following is a detailed description of the logic of "base year" selection in GREET and the consequent adjustment of estimates for subsequent years.

   a. If you selected more than one simulation year in the window shown in Figure 2.11, GREETGUI selects one simulation year as its "base year" to use in presenting options and estimates for available technologies associated with the selected fuel production pathways.
   b. Specifically, GREETGUI selects the simulation year closest to 2010 as its "base" year, and then displays the default estimates associated with pertinent technologies in GREET for that "base year." The simulation year closest to 2010 is selected because many key default input assumptions, especially those with distribution functions, are made for year 2010.
   c. If you modify technology estimates of the base year, GREETGUI makes proportionate adjustments to the corresponding estimates of all subsequent simulation years. For example, if you change the share of coal-generated electricity in the U.S. average mix from 50.2% to 51% for the year 2010, GREETGUI will adjust the

coal-generated electricity share estimates for all simulation years subsequent to 2010 in GREET by the same percentage, which in this case is 1.6%.

Note that GREETGUI does not adjust technology options and estimates for simulation years before 2010 because the shares of a new technology should not affect past historical trends.

Figure 2.15 shows a typical pathway simulation options screen in GREETGUI, showing blue tabs for the selected feedstock and fuel types. The Electricity tab always appears, regardless of the transportation fuel pathways selected. This is because electricity is used in the activities for all fuel pathways.

There are two types of electricity generation mix, the marginal mix and the average mix. The marginal mix is used for the production of hydrogen via electrolysis at refueling stations, and for supplying electricity to electric vehicles (EVs) and grid-connected (GC) hybrid-electric vehicles (HEVs). The average mix is used for the well-to-pump (WTP) stage of the fuel cycle. Each blue tab displays the input fields and options for its pathway group.

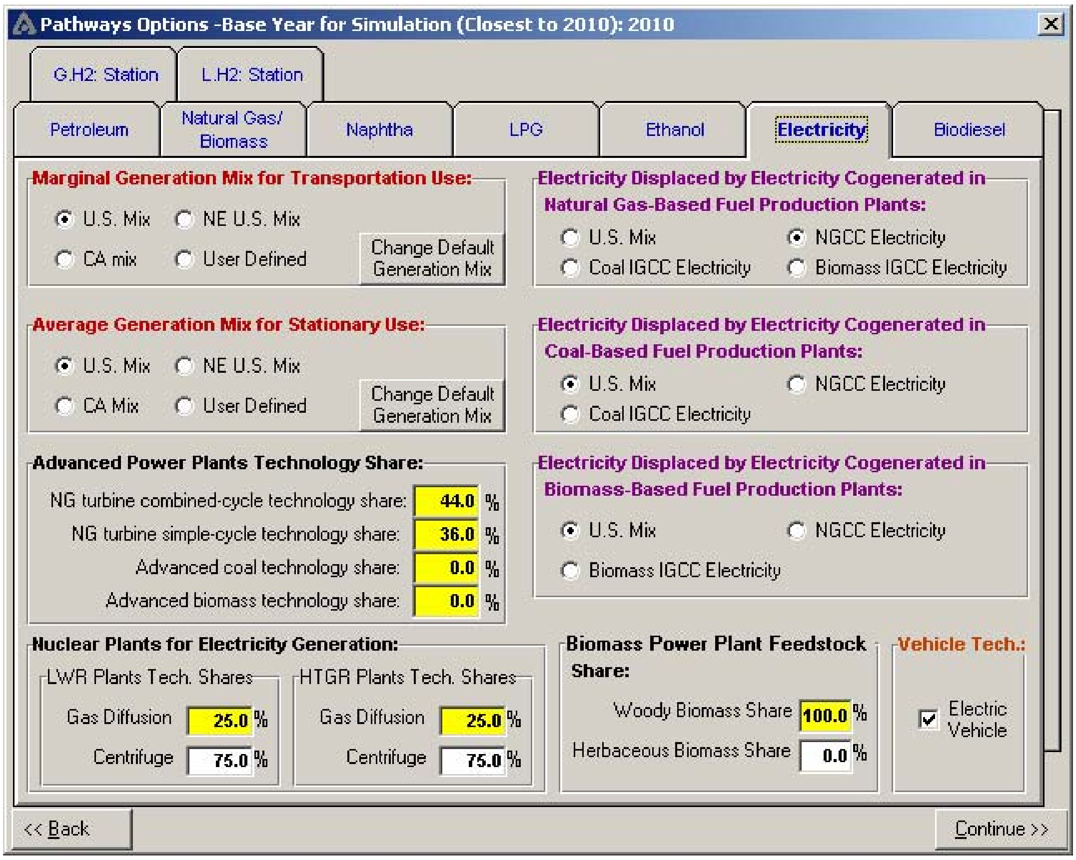



**FIGURE 2.15 Typical pathway simulation options screen in GREETGUI**

Note that, throughout the GREETGUI program, all the yellow fields are input fields that may be edited/changed. You may click or double-click inside the yellow field to modify the GREET default value in that field. As previously mentioned, the default estimates shown in the yellow fields are extracted for the base year from the lookup tables in GREET.

Although you cannot view GREET's lookup tables, any changes you make to the base year's default estimate result in automatic adjustment of all subsequent years' default estimates in corresponding GREET lookup tables by the same percentage change made to the base year's estimate. Holding the mouse cursor on any of the input fields displays a tool-tip box describing the significance of that field.

4. The Petroleum and Natural Gas/Biomass tabs have several subgroups of pathways, divided into convenient sub-tabs, which are displayed in Red as shown in Figure 2.16. Before proceeding, GREETGUI reminds you to review all the displayed blue and red tabs before continuing to the next window. This ensures that you are aware of all key assumptions involved in the simulation.

   Click the **Continue** button to proceed, or click the **Back** button to review the earlier phase of market shares selections.

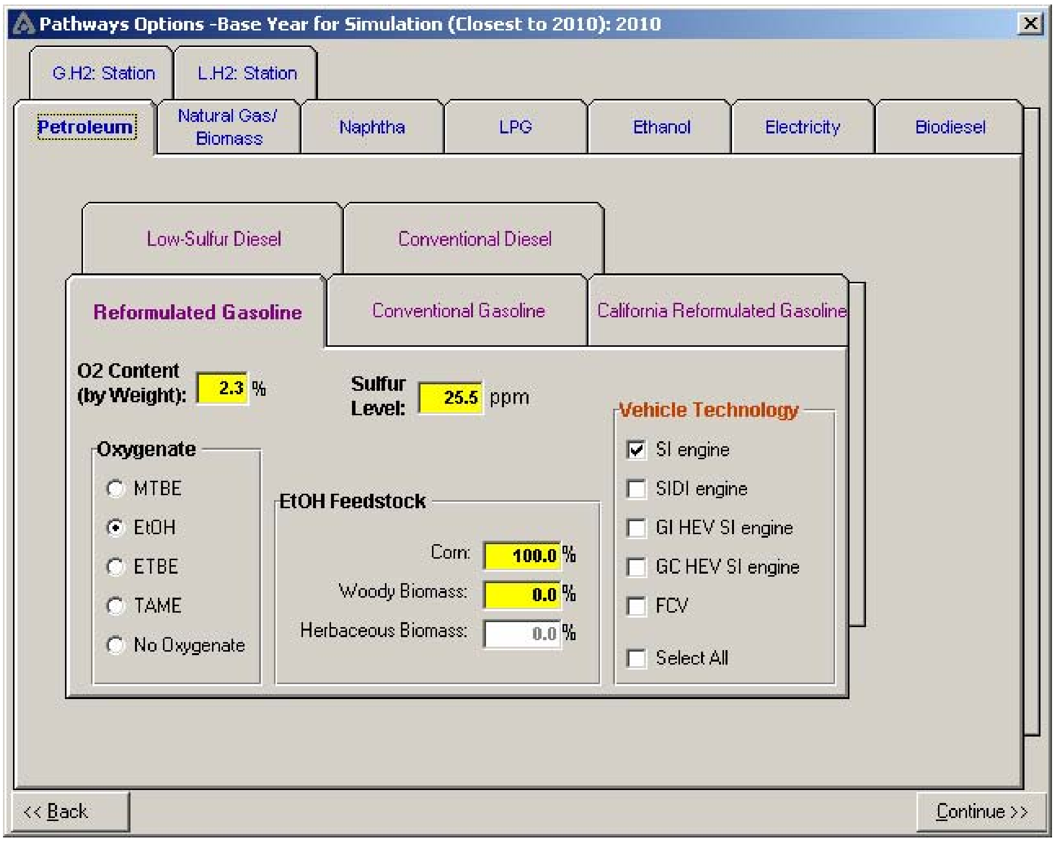



**FIGURE 2.16 Petroleum pathways simulation options in GREETGUI**

5. A window labeled "Simulation Options for Alternative Fuel Blends" appears (Figure 2.17), which allows you to select the shares of the alternative fuels to blend with gasoline or diesel fuels. You may adjust the default values of blend shares shown in the yellow fields, by typing the preferred numbers in place of the defaults. Note that the shares of reformulated/conventional gasoline and of low-sulfur/conventional diesel for blending with alternative fuels are consistent with the market shares specified in Figure 2.14, with the exception of low-level ethanol for blending with gasoline, where 100% conventional gasoline is used for blending (ethanol blending in reformulated gasoline is simulated in GREET separately).

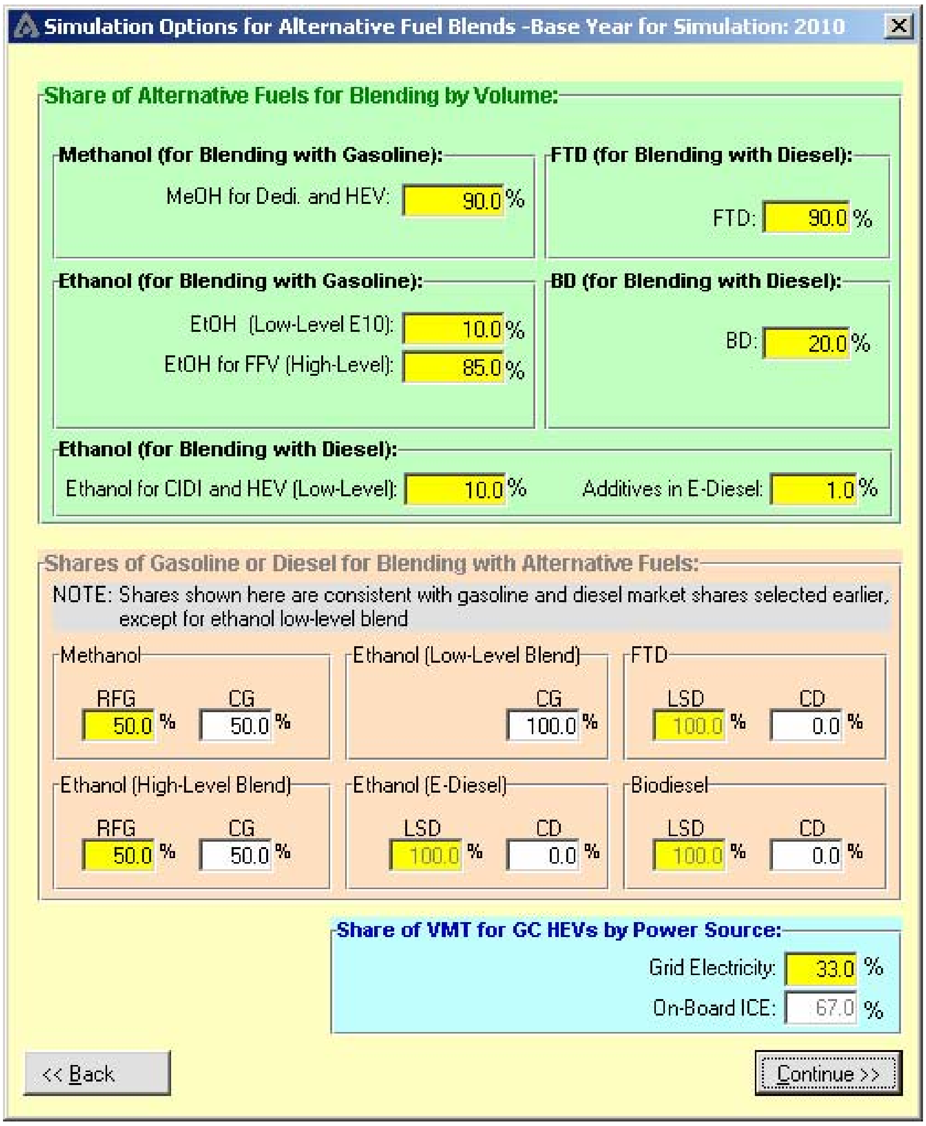



**FIGURE 2.17 Alternative fuel blends simulation options screen**

Click the **Continue** button to proceed, or click the **Back** button to review the pathways technology options in the previous window.

6. After you complete the second phase of technology selection/specification, a pop-up window will appear (Figure 2.18), offering the following three options:
   - **Yes — Continue**: This takes you to the third and last phase of GREETGUI, where you can review/change parametric assumptions associated with production and distribution of the selected fuel types. If clicked, GREETGUI proceeds to view and/or change the parametric assumptions of the base year. The base year is the year closest to 2010, for which GREET model has its estimates with high confidence.
   - **No — Review selected scenario options**: This allows you to return to the beginning of the previous technology selection/specification window, where changes can be made to the selections made in the above described steps by clicking on the appropriate pathway tabs and making new selections as desired.
   - **No — Start a new session without saving:** This allows you to abort the current GREETGUI session and restart from the beginning. Note: this option discards any selections you have already made in the current session.

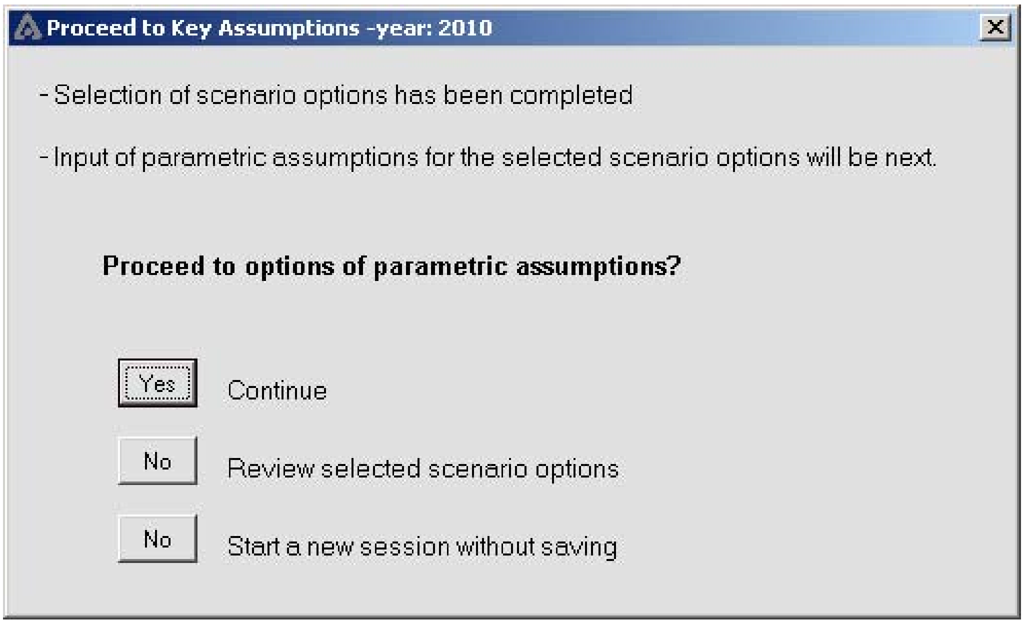



**FIGURE 2.18 End of pathways simulation options selection screen**

7. When you click on the **Yes — Continue** button, the program proceeds to the third phase of key assumptions for the selected fuel pathways and scenarios. A window displaying the simulation options for the base year's parametric assumptions will show, see Figure 2.19.

### 2.4.4 Altering GREET's Key Assumptions

As a spreadsheet model running in the background, GREET incorporates estimates of key assumptions in lookup tables for the range of years from 1990 to 2020, arranged in five-year intervals. Only the base year's estimates of the key assumptions are presented for review or modification. The assumptions for all other years in the lookup tables are automatically adjusted to reflect the percentage changes you made to the base year's assumptions.

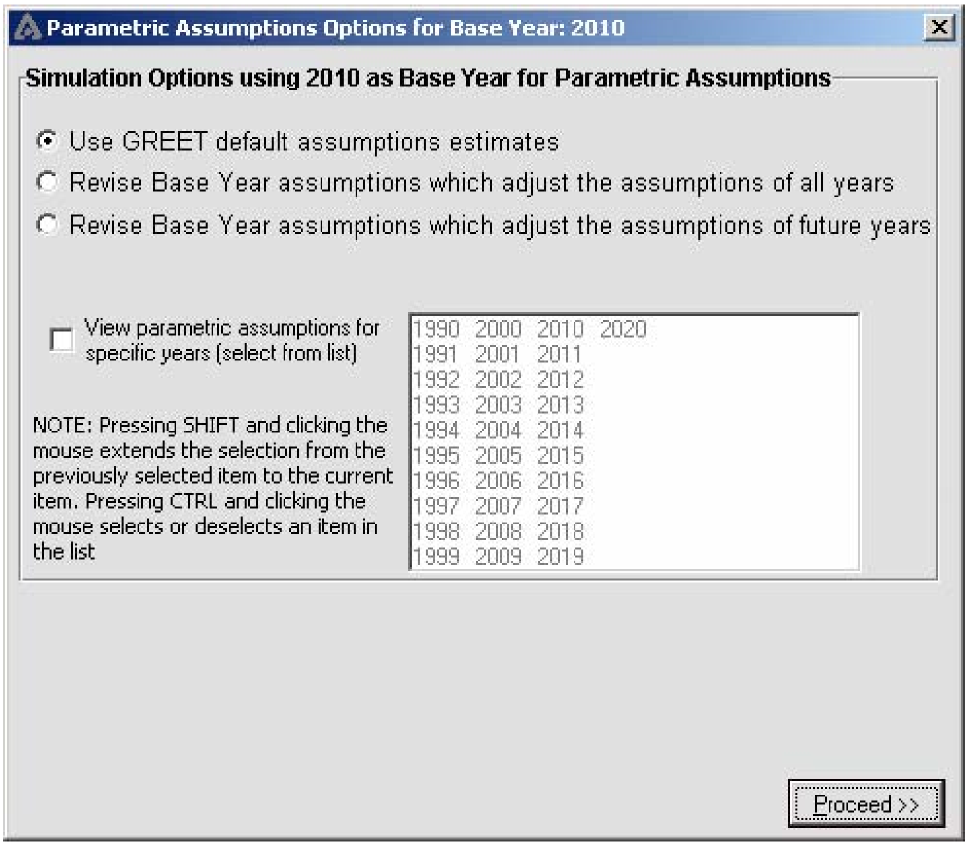


**FIGURE 2.19 Parametric assumptions simulation options**

1. When the window shown in Figure 2.19 appears, you may select one of three options:

   - Use GREET default assumptions estimates,
   - Revise Base Year assumptions which adjust the assumptions of all years (by the same percentage change made to the base year's assumptions), or
   - Revise Base Year assumptions which adjust the assumptions of future years (by the same percentage change made to the base year's assumptions).

   Selecting **Use GREET default assumptions** allows you to view the GREET default assumptions in the subsequent assumptions screens, but without being able to modify or change them.

Selecting **Revise Base Year assumptions which adjust the assumptions of all years** allows you to revise the base year's assumptions and automatically adjusts all other years' assumptions in the GREET lookup tables by the same percentage change made to the base year's assumptions. Choose this option when you wish to revise the default assumptions upward or downward in the entire lookup table by simply changing the default assumption of the base year.

Selecting **Revise Base Year assumptions which adjust the assumptions of future years** allows you to revise the base year's assumptions and automatically adjusts only the future years' assumptions in the GREET lookup tables by the same percentage change made to the base year's assumptions. Choose this option when you want to revise the default assumptions of the base year and of all subsequent years up to 2020, while leaving the assumptions of the earlier years (prior to the starting year of a selected simulation period) unchanged at their original default values.

2. Although you cannot modify GREET's lookup tables for the key assumptions in the subsequent assumptions screens, you may check a box to view the parametric assumptions for any of the simulation years by selecting those years from the displayed list in the window shown in Figure 2.19.

   Click the **Proceed** button to continue.

   The key assumptions, listed in table format, appear in three successive windows labeled, "Fuel Production Assumptions," "Feedstock and Fuel Transportation Assumptions," and "Vehicle Operation Assumptions." Note that only the key assumptions relevant to the selected fuel pathways are displayed in GREETGUI. Other assumptions used by the GREET model are not displayed in GREETGUI and therefore, you cannot view or change them through the GUI program. However, you may always go to the GREET model in Excel to change any of the parametric assumptions.

3. The first key assumptions window (Figure 2.20) shows the "Fuel Production Assumptions," which may include one or more blue tabs depending on the fuel pathways selected. You may edit the yellow cells in the table of each tab by single-clicking in the cell to modify any of the key assumptions for the base year as desired.

   After reviewing the fuel production assumptions, click the **Continue** button to proceed to the next key assumptions screen.

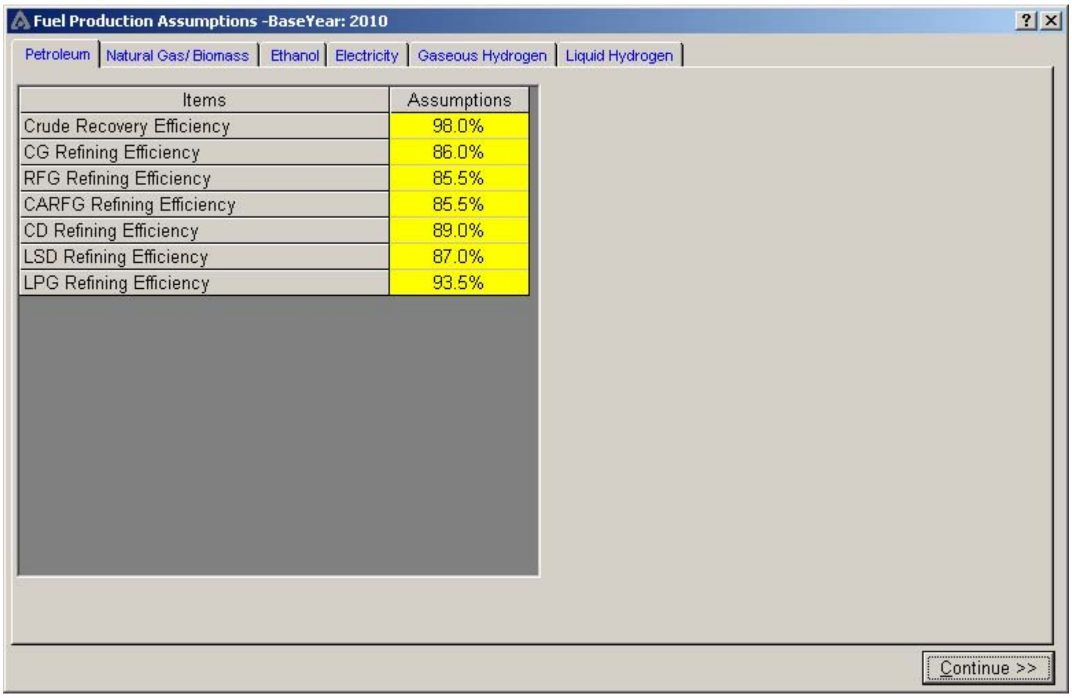



**FIGURE 2.20 Typical fuel production assumptions screen**

4. The second key assumptions window (Figure 2.21), shows the “Feedstock and Fuel Transportation Assumptions,” which may include one or more blue tabs, depending on the fuel pathways selected.

   The **Transportation Modes** tab includes the key assumptions for the fuel transportation modes of the feedstock and fuel types in the selected fuel pathways.

   The **LNG and $LH_2$ Boiloff** tab includes the key assumptions for the boiloff of liquefied natural gas (LNG) and/or liquid hydrogen ($LH_2$) during transportation.

   The **Ocean Tanker Size** tab includes the key assumptions about the ocean tanker size for the selected feedstock and fuel types, which are imported from overseas or transported from Alaska (in the case of petroleum crude).

   You can edit all yellow cells in the displayed table by single-clicking in the cell to modify the key assumptions as desired.

   Note that this window appears only once throughout the entire running session, since its assumptions do not depend on the simulation year.

   After reviewing/editing the “Feedstock and Fuel Transportation Assumptions,” click the **Continue** button to continue to the final dialogue box or the **Back** button to review the previous window of “Fuel Production Assumptions.”

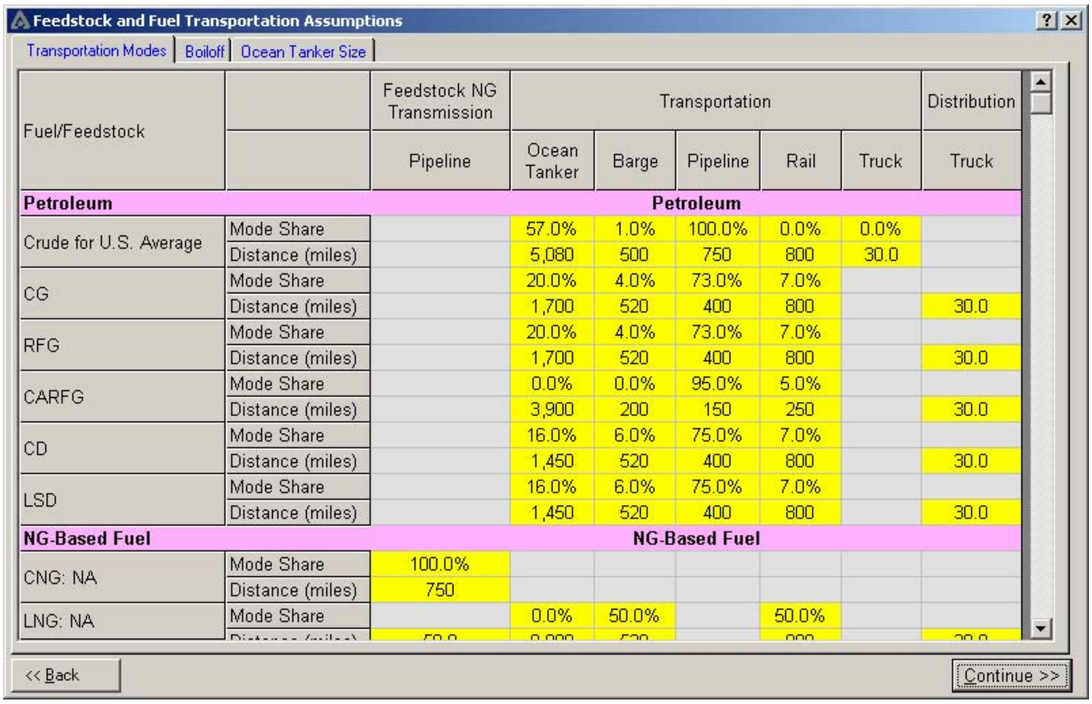



**FIGURE 2.21 Typical transportation assumptions screen**

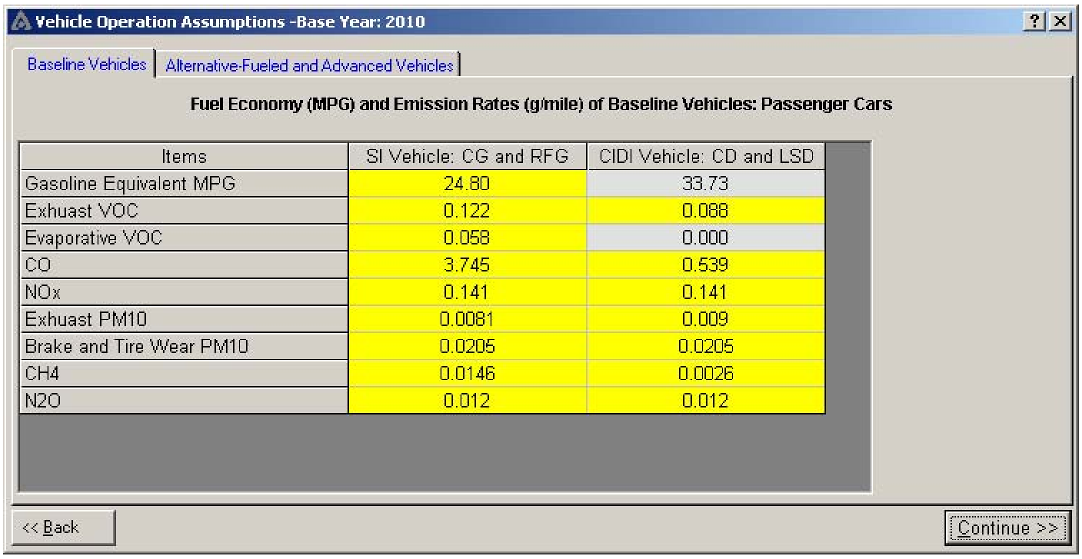
5. The third key assumptions window (Figure 2.22), shows the "Vehicle Operation Assumptions," which includes two blue tabs (see below).

   The **Baseline Vehicles** tab includes the key assumptions for the fuel economy and emission rates of the baseline vehicles, i.e., conventional gasoline and diesel vehicles.

   The **Alternative Fuel and Advanced Vehicles** tab includes the key assumptions for the fuel economy and emission ratios of the alternative fueled and advanced vehicle technologies relative to the baseline vehicles.

   You can edit the yellow cells by single-clicking in the cell to modify the key assumptions as desired. The gray cells cannot be edited because no input is required for these cells.

   After reviewing/editing the vehicle operation assumptions, click the **Continue** button to continue to the final dialogue box or the **Back** button to review any of the previous key assumptions windows.




| Items | SI Vehicle: CG and RFG | CIDI Vehicle: CD and LSD |
|---|---|---|
| Gasoline Equivalent MPG | 24.80 | 33.73 |
| Exhuast VOC | 0.122 | 0.088 |
| Evaporative VOC | 0.058 | 0.000 |
| CO | 3.745 | 0.539 |
| NOx | 0.141 | 0.141 |
| Exhuast PM10 | 0.0081 | 0.009 |
| Brake and Tire Wear PM10 | 0.0205 | 0.0205 |
| CH4 | 0.0146 | 0.0026 |
| N2O | 0.012 | 0.012 |

**FIGURE 2.22 Typical vehicle operation assumptions screen**

6. After all key assumptions have been reviewed and/or modified; another window shown in Figure 2.23 presents three options:

   - **Yes — Continue:** Selecting this option allows you to complete the GREET simulation. GREETGUI (a) configures the underlying GREET model in the background based on your defined scenario options and parametric assumptions, (b) runs the main GREET Excel program in the background for all simulation years, and (c) exports the output results into another Excel file that you identified at the beginning of the running session.
   - **No — Review parametric assumptions:** Selecting this option allows you to return to the parametric assumptions windows and review the selections and/or changes earlier made in these windows.
   - **No — Start a new session without saving:** Selecting this option allows you to abort the current GREETGUI session and restart from the beginning. Note: this option discards any selections you have already made during the current session.

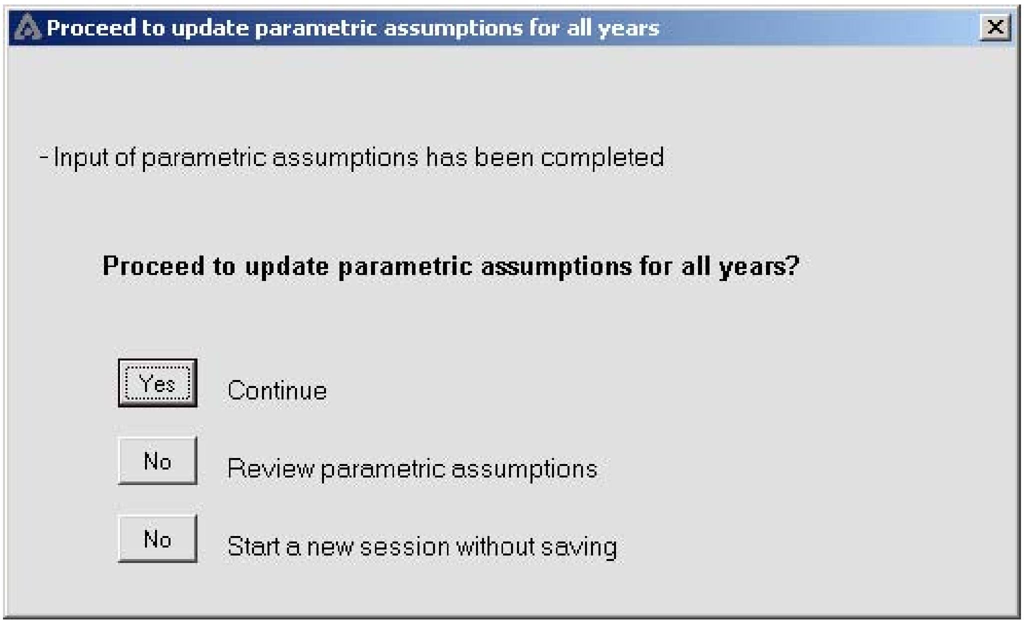


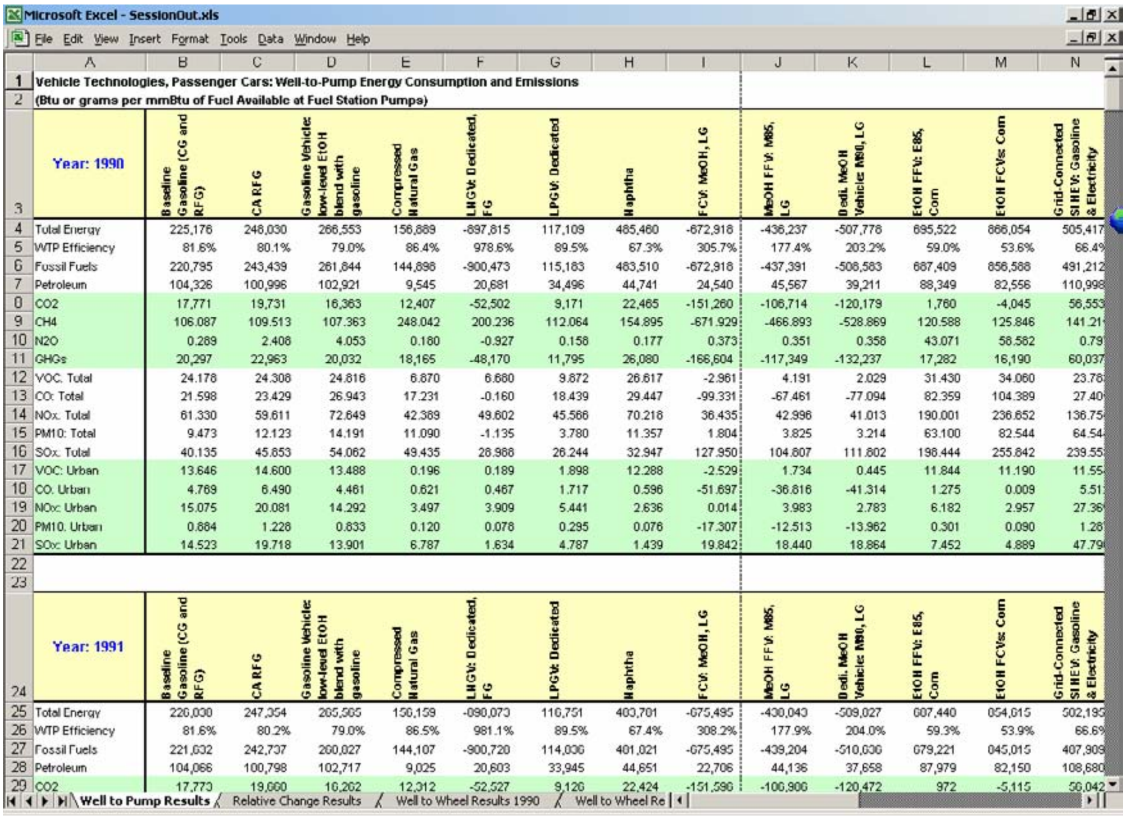

**FIGURE 2.23 End of parametric assumptions screen**

After GREETGUI completes its running session, it generates an output file, which displays the results of the GREET model simulation for the selected pathways scenarios (Figure 2.24).

The first sheet in the output file displays the **well-to-pump results for all simulation years**.

The second sheet displays the **relative changes of the well-to-wheels output results for the advanced vehicles compared to the corresponding baseline conventional vehicle**.

The **per-mile well-to-wheels results for each of the simulation years** are displayed in the remainder of the sheets in the output file.



Microsoft Excel - SessionOut.xls

Vehicle Technologies, Passenger Cars: Well-to-Pump Energy Consumption and Emissions
(Btu or grams per mmBtu of Fuel Available at Fuel Station Pumps)

| Year: 1990 | Baseline Gasoline (CG and RFG) | CA RFG | Gasoline Vehicle: low-level EtOH blend with gasoline | Compressed Natural Gas | LNGV: Dedicated, FG | LPGV: Dedicated | Naphtha | FCV: MeOH, LG | MeOH FFV: M85, LG | Dedi. MeOH Vehicle: M90, LG | EtOH FFV: E85, Corn | EtOH FCVs: Corn | Grid-Connected SI HEV: Gasoline & Electricity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Energy | 225,176 | 248,030 | 266,553 | 156,889 | -897,815 | 117,109 | 485,460 | -672,918 | -436,237 | -507,778 | 695,522 | 866,054 | 505,417 |
| WTP Efficiency | 81.6% | 80.1% | 79.0% | 86.4% | 978.6% | 89.5% | 67.3% | 305.7% | 177.4% | 203.2% | 59.0% | 53.6% | 66.4% |
| Fossil Fuels | 220,795 | 243,439 | 261,844 | 144,898 | -900,473 | 115,183 | 483,510 | -672,918 | -437,391 | -508,583 | 687,409 | 856,588 | 491,212 |
| Petroleum | 104,326 | 100,996 | 102,921 | 9,545 | 20,681 | 34,496 | 44,741 | 24,540 | 45,567 | 39,211 | 88,349 | 82,556 | 110,998 |
| CO2 | 17,771 | 19,731 | 16,363 | 12,407 | -52,502 | 9,171 | 22,465 | -151,260 | -106,714 | -120,179 | 1,760 | -4,045 | 56,553 |
| CH4 | 106.087 | 109.513 | 107.363 | 248.042 | 200.236 | 112.064 | 154.895 | -671.929 | -466.893 | -528.869 | 120.588 | 125.846 | 141.21 |
| N2O | 0.289 | 2.408 | 4.053 | 0.180 | -0.927 | 0.158 | 0.177 | 0.373 | 0.351 | 0.358 | 43.071 | 58.582 | 0.79 |
| GHGs | 20,297 | 22,963 | 20,032 | 18,165 | -48,170 | 11,795 | 26,080 | -166,604 | -117,349 | -132,237 | 17,282 | 16,190 | 60,037 |
| VOC: Total | 24.178 | 24.308 | 24.816 | 6.870 | 6.680 | 9.872 | 26.617 | -2.961 | 4.191 | 2.029 | 31.430 | 34.060 | 23.78 |
| CO: Total | 21.598 | 23.429 | 26.943 | 17.231 | -0.160 | 18.439 | 29.447 | -99.331 | -67.461 | -77.094 | 82.359 | 104.389 | 27.40 |
| NOx: Total | 61.330 | 59.611 | 72.649 | 42.389 | 49.602 | 45.566 | 70.218 | 36.435 | 42.996 | 41.013 | 190.001 | 236.652 | 136.75 |
| PM10: Total | 9.473 | 12.123 | 14.191 | 11.090 | -1.135 | 3.780 | 11.357 | 1.804 | 3.825 | 3.214 | 63.100 | 82.544 | 64.54 |
| SOx: Total | 40.135 | 45.853 | 54.062 | 49.435 | 28.988 | 26.244 | 32.947 | 127.950 | 104.807 | 111.802 | 198.444 | 255.842 | 239.55 |
| VOC: Urban | 13.646 | 14.600 | 13.488 | 0.196 | 0.189 | 1.898 | 12.288 | -2.529 | 1.734 | 0.445 | 11.844 | 11.190 | 11.55 |
| CO: Urban | 4.769 | 6.490 | 4.461 | 0.621 | 0.467 | 1.717 | 0.596 | -51.697 | -36.816 | -41.314 | 1.275 | 0.009 | 5.51 |
| NOx: Urban | 15.075 | 20.081 | 14.292 | 3.497 | 3.909 | 5.441 | 2.636 | 0.014 | 3.983 | 2.783 | 6.182 | 2.957 | 27.36 |
| PM10: Urban | 0.884 | 1.228 | 0.833 | 0.120 | 0.078 | 0.295 | 0.076 | -17.307 | -12.513 | -13.962 | 0.301 | 0.090 | 1.28 |
| SOx: Urban | 14.523 | 19.718 | 13.901 | 6.787 | 1.634 | 4.787 | 1.439 | 19.842 | 18.440 | 18.864 | 7.452 | 4.889 | 47.79 |

| Year: 1991 | Baseline Gasoline (CG and RFG) | CA RFG | Gasoline Vehicle: low-level EtOH blend with gasoline | Compressed Natural Gas | LNGV: Dedicated, FG | LPGV: Dedicated | Naphtha | FCV: MeOH, LG | MeOH FFV: M85, LG | Dedi. MeOH Vehicle: M90, LG | EtOH FFV: E85, Corn | EtOH FCVs: Corn | Grid-Connected SI HEV: Gasoline & Electricity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Energy | 226,030 | 247,354 | 265,565 | 156,159 | -898,073 | 116,751 | 483,701 | -675,495 | -438,043 | -509,027 | 687,440 | 854,015 | 502,195 |
| WTP Efficiency | 81.6% | 80.2% | 79.0% | 86.5% | 981.1% | 89.5% | 67.4% | 308.2% | 177.9% | 204.0% | 59.3% | 53.9% | 66.6% |
| Fossil Fuels | 221,632 | 242,737 | 260,027 | 144,107 | -900,720 | 114,036 | 481,021 | -675,495 | -439,204 | -510,636 | 679,221 | 845,015 | 487,909 |
| Petroleum | 104,066 | 100,798 | 102,717 | 9,025 | 20,603 | 33,945 | 44,651 | 22,706 | 44,136 | 37,658 | 87,979 | 82,150 | 108,680 |
| CO2 | 17,773 | 19,660 | 16,262 | 12,312 | -52,527 | 9,126 | 22,424 | -151,596 | -106,906 | -120,472 | 972 | -5,115 | 56,042 |

Well to Pump Results | Relative Change Results | Well to Wheel Results 1990 | Well to Wheel Re

**FIGURE 2.24 GREETGUI output file**

GREETGUI also generates a second Excel file, which keeps a record of all inputs during a particular GREETGUI session (Figure 2.25).

The first sheet in the inputs log file displays the **fuel pathways selections and inputs you made for the base year**.

The second sheet displays the **inputs made to the fuel blending options for the base year**.

The third sheet displays the **market shares for all selected feedstock and fuel types, for all the simulation years**.

The fourth, fifth and sixth sheets display **user inputs to the fuel production assumptions**, **transportation and distribution assumptions**, and **vehicle operation assumptions for the base year**, respectively.

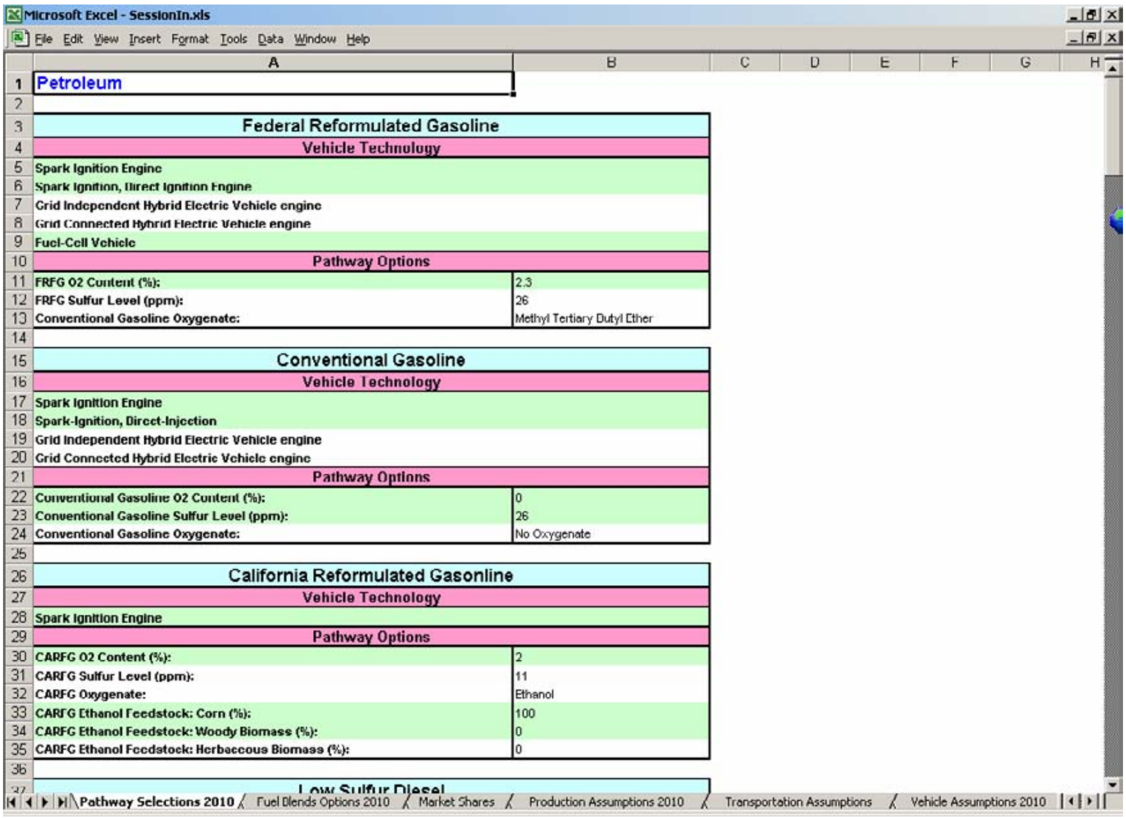



**FIGURE 2.25 GREETGUI inputs log file**

7. As GREETGUI closes, you will be prompted as to whether or not to save the concluded session as a ".GAF" file (Figure 2.26).

   To save the simulation inputs you have made so you can run GREETGUI again with those inputs, click the **Yes** button. It may take up to one minute to save the completed session.

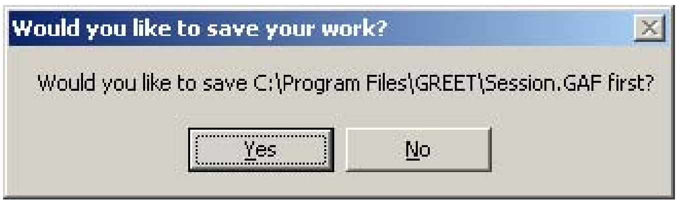



**FIGURE 2.26 GREETGUI prompt to save screen**

### 2.4.5. Using GREET for Stochastic Simulations

As mentioned in section 2.4.2, "Beginning a GREETGUI Session," you may use GREETGUI to configure the GREET model for a stochastic simulation rather than a point estimation. The GREET model takes into account the probability distributions of key input parameters such as energy efficiencies and emission factors associated with the feedstock recovery and fuel production processes, and produces the results in the form of statistical distributions.

1. To configure the GREET model for a stochastic simulation using GREETGUI, select "**Yes, I want to run Stochastic Simulations"** in the Stochastic Simulation option frame shown in Figure 2.11. Note that stochastic simulations are possible only for a single target year for each simulation in the current GREET version.

2. Continue with the GREETGUI session as explained in sections 2.4.2 through 2.4.4. At the end of your session, click the **Continue** button (see Figure 2.23).

   GREETGUI starts configuring the GREET spreadsheet model in the background by adjusting the probability distributions of all key input parameters around their new mean values for the selected target year, and saves a copy of the configured GREET model into the GREETGUI program folder.

   Once the GREET file has been created, a pop-up window will display a message with the file name and location (Figure 2.27). GREETGUI appends "ST" to the user-specified session name, as shown in Figure 2.27. you may select **Yes** to load the configured file in the Microsoft® Excel to conduct stochastic simulations for now, or **No** to save this GREET file and go back to GREETGUI program main screen (see Figure 2.8).

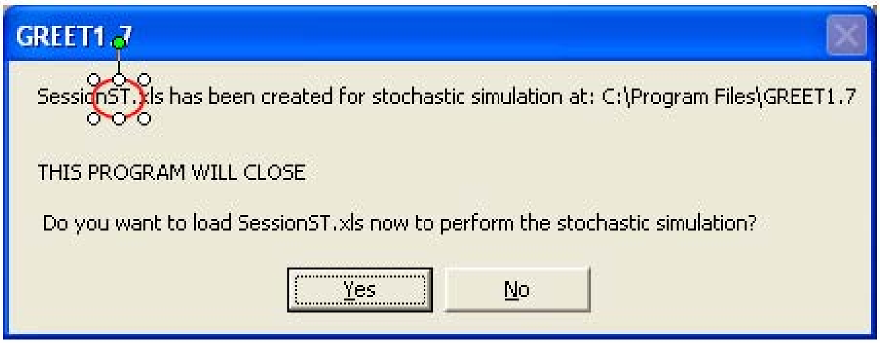



**FIGURE 2.27 Message box about the configured file for stochastic simulation**

3. To run stochastic simulations for a specific GREET file (e.g., SessionST.xls), go to View>Toolbars in the Microsoft® Excel, click to activate the "Stochastic Simulation" toolbar, as shown in Figure 2.28.

4. A command bar with all the command buttons required for the stochastic simulation process appears as shown in Figure 2.29. The GREET stochastic capability has been implemented through the command bar containing five buttons for the five main steps of stochastic simulations. The stochastic simulation feature was created by Vishwamitra Research Institute (VRI) for ANL. The user can review or modify the GREET default distribution functions, select sampling technique, and set up forecast cells for stochastic simulations.

   Note that input cells in GREET with built-in distribution functions are colored in Green. The cells colored in Blue are GREET forecast cells for running stochastic simulations.

   **For detailed instructions on stochastic simulations, please refer to the *User Manual for Stochastic Simulation Capability in GREET* provided along with the GREET1.7 model, which is available from the GREET website at: http://www.transportation.anl.gov/software/GREET/index.html.**

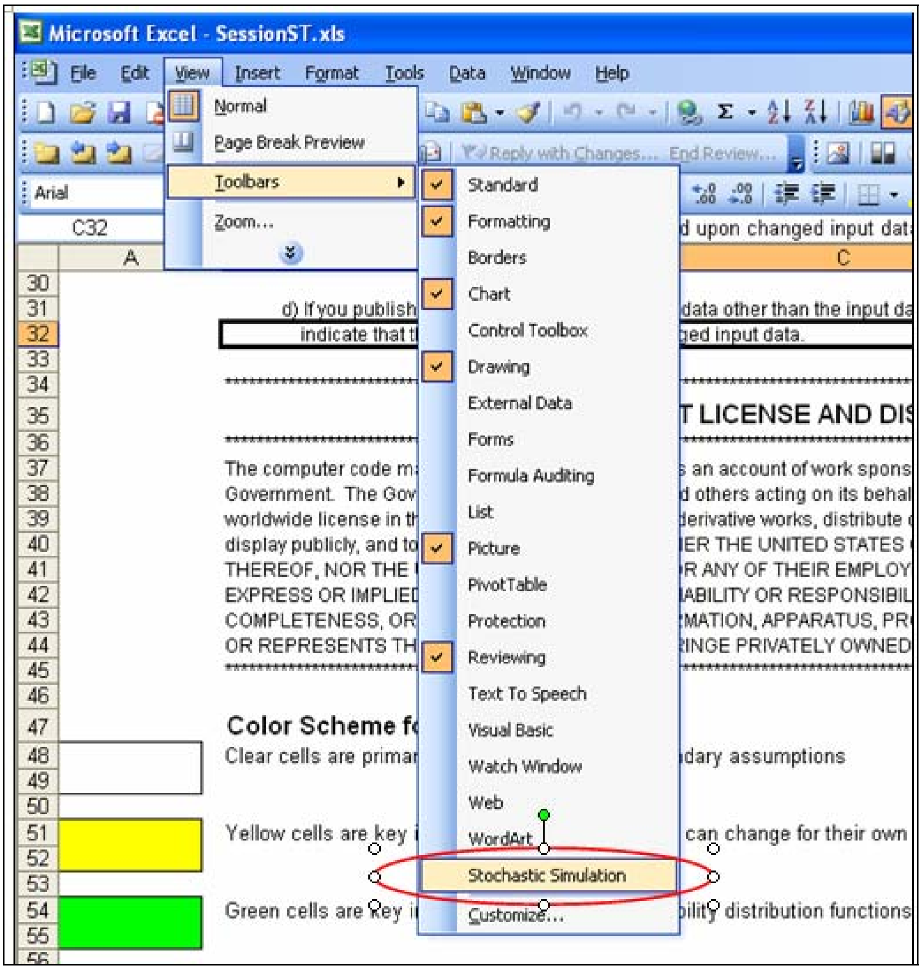


**FIGURE 2.28 Loading the "Stochastic Simulation" Toolbar**

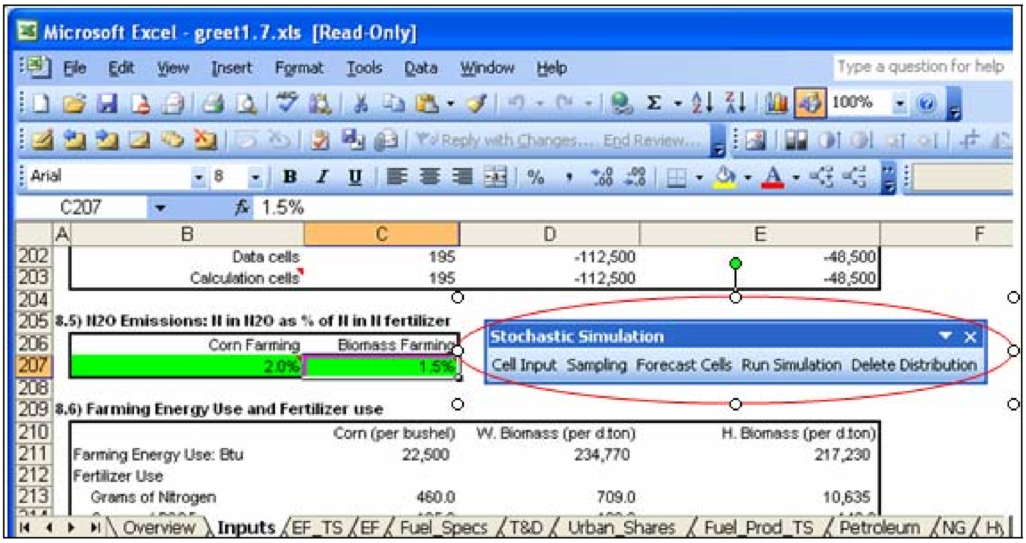


**FIGURE 2.29 Stochastic Simulation Command Bar**

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# 3. GREET Simulation Options

This chapter provides information on key parametric assumptions and pathway simulation options used in various fuel-cycle simulations. The GREET methodologies for fuel-cycle simulations are not discussed in this manual. Publications that explain the GREET methodologies are available for download from the Argonne National Laboratory transportation website at http://www.transportation.anl.gov/software/GREET/publications.html. The following is a list of the key publications for the GREET fuel-cycle model:

1) Wu, M., Y. Wu, and M. Wang, 2005. Mobility Chains Analysis of Technologies for Passenger Cars and Light-Duty Vehicles Fueled with Biofuels: Application of the GREET Model to the Role of Biomass in America's Energy Future (RBAEF) Project, May.
2) Brinkman, N., M. Wang, T. Weber, and T. Darlington, 2005. Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems — A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions, May.
3) Wang, M., 2001, Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies, ANL/ESD-TM163, Argonne National Laboratory, Argonne, Ill., June.
4) General Motors Corporation, Argonne National Laboratory, BP, ExxonMobil, and Shell, 2001, Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems — a North American Analysis, June.
5) Wang, M., 1999a, GREET 1.5 — Transportation Fuel-Cycle Model, Volume 1: Methodology, Development, Use, and Results, ANL/ESD-39, Vol.1, Argonne National Laboratory, Argonne, Ill., Aug.

## 3.1 Market Shares of Fuel Production Options for Given Transportation Fuels

GREETGUI presents market shares for transportation fuels for the simulation years you chose in tabular form. These include (see Figure 3.1):

- **Gasoline types' market shares**, which specify the split between reformulated gasoline (RFG) and conventional gasoline (CG) market shares.
- **Diesel fuel types' market shares**, which specify the split between low-sulfur diesel (LSD) and conventional diesel (CD) market shares.
- **Gaseous $H_2$ ($GH_2$) production shares**, which specify the split between central plant and refueling station production market shares. Since gaseous hydrogen can be produced from different feedstock sources, there are two more sub-categories of market shares for gaseous hydrogen: (a) **gaseous $H_2$ central production feedstock shares,** which specify the split of feedstock market shares among natural gas (NG), solar energy (photovoltaic and electrolysis), nuclear energy (either with thermo-chemical water cracking or high-temperature electrolysis),

coal, and biomass; and (b) **gaseous $H_2$ station production feedstock shares**, which specify the split of feedstock market shares among NG, electricity, ethanol (EtOH) and methanol (MeOH).

- **Liquid $H_2$ ($LH_2$) production shares,** which specify the split between central plant and refueling station production market shares. Similar to GH2 production, since liquid hydrogen can be produced from different feedstock sources, there are two more sub-categories of market shares for liquid hydrogen: (a) **liquid $H_2$ central production feedstock shares**, which specify the split of feedstock market shares among NG, solar energy (photovoltaic and electrolysis), nuclear energy (either with thermo-chemical water cracking or high-temperature electrolysis), coal, and biomass; and (b) **liquid $H_2$ station production feedstock shares**, which specify the split of feedstock market shares among NG, electricity, ethanol and methanol.
- **Liquefied petroleum gas (LPG) feedstock shares,** which specify the split between NG and crude feedstock market shares.
- **Ethanol feedstock shares,** which specify the split between corn, woody biomass and herbaceous biomass feedstock market shares.

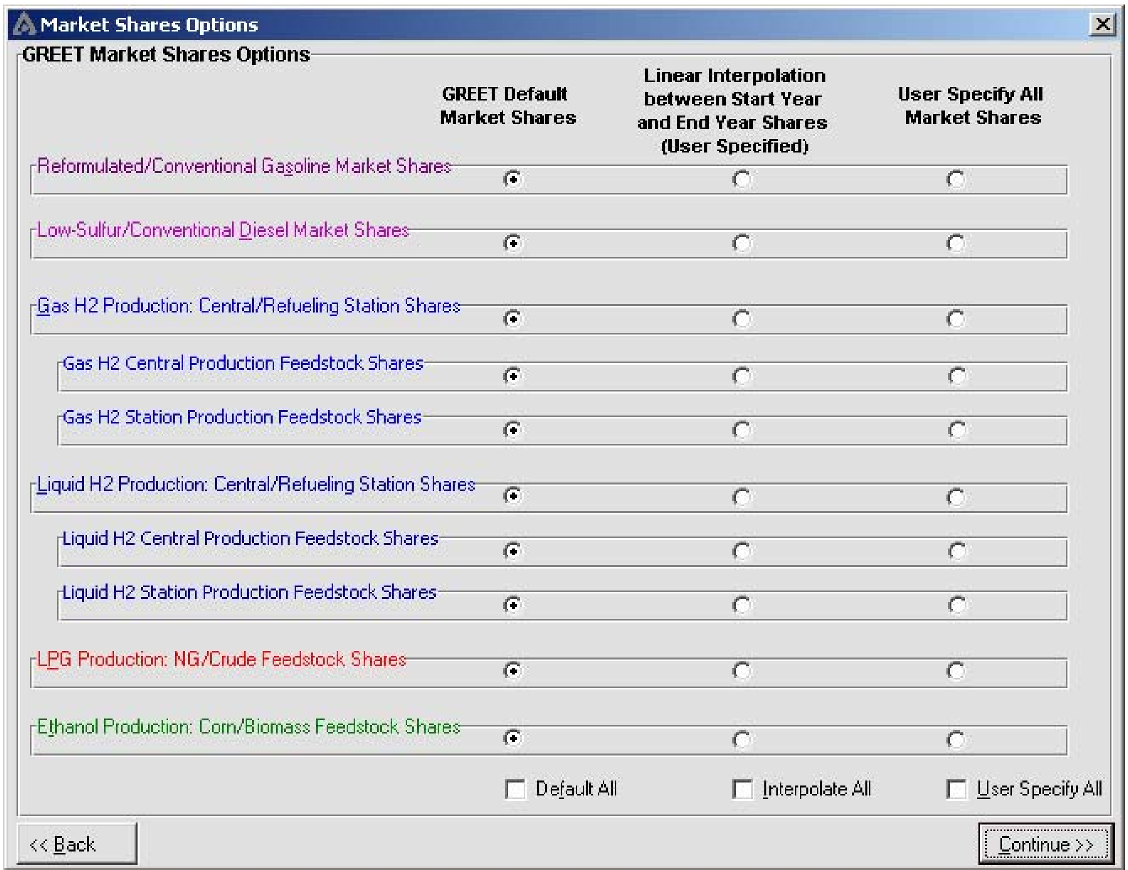


**FIGURE 3.1 GREET market shares options for fuel production**

Market shares in the GREETGUI program are linked to lookup (time-series) tables in the underlying GREET spreadsheet model. The time-series tables have been developed to account for expected changes in the market shares over time. Table 3.1 lists the default market shares for the above mentioned six transportation fuels in GREET. The following paragraphs explain the rationale behind the default GREET shares shown in Table 3.1.

The market shares of reformulated gasoline and conventional gasoline shown in Table 3.1 are based on the expectation that RFG market share will continue to increase over time in the U.S., and could eventually displace conventional gasoline by the year 2020.

The market shares for low-sulfur diesel shown in Table 3.1 are based on the federal requirement that starting in 2006, all diesel fuel being sold in the U.S. must meet the low-sulfur diesel standard. For on-road motor vehicles, this standard calls for sulfur levels below 15 ppm by weight.

$H_2$ is a new transportation fuel for use in the future; therefore, all the $H_2$ production options for transportation purposes are currently under evaluation. For this version of GREET, the default $H_2$ production option is assumed to be produced from NG via steam methane reforming (SMR) at refueling stations, which is shown in Tables 3.1 through 3.5. However, you may easily simulate any other $H_2$ production options by changing the $H_2$ production feedstock and market shares through the GREETGUI menu.

**In central plants, $H_2$ can be produced from the following feedstock sources:**
- NG via SMR
- Solar energy via photovoltaic
- Nuclear energy via thermo-chemical water cracking (TCWC) using heat from high-temperature gas-cooled reactor (HTGR)
- Nuclear energy via high-temperature electrolysis of water
- Coal via gasification
- Biomass via gasification

The default shares of $GH_2$ and $LH_2$ produced in central plants from various feedstock sources are shown in Tables 3.2 and 3.3, respectively. Noted that although the NG via SMR option is used as the default feedstock for $H_2$ production in central plants from 1990 to 2020, this option does not impact the simulation results since the default market share of central plant production in GREET is zero, see Table 3.1.

**At refueling stations, $H_2$ can be produced from the following feedstock sources:**
- NG via SMR
- Electricity via electrolysis of water
- Reforming of EtOH
- Reforming of MeOH

The default shares of various feedstock sources contributing to $GH_2$ and $LH_2$ production at refueling stations are developed in GREET as shown in Tables 3.4 and 3.5, respectively.

The market share of NG-based LPG is expected to increase over time in the U.S. at the expense of crude-based LPG as shown in Table 3.1, primarily due to the anticipated increase in LPG imports from other countries to the U.S.

At present, fuel ethanol in the U.S. is produced primarily from corn. Since cellulosic biomass-based ethanol is still in the R&D stage, the GREET model assumes corn to be the only feedstock for ethanol production in the U.S. until 2020 (Table 3.1). Again, you can change ethanol production options readily in GREET.

**TABLE 3.1 Default Market Shares for Selected Transportation Fuels**

| | Gasoline | | Diesel | | $GH_2$ | |
|---|---|---|---|---|---|---|
| Year | RFG | CG | LSD | CD | Central Plants Production | Refueling Stations Production |
| 1990 | 0% | 100% | 0% | 100% | 0% | 100% |
| 1995 | 15% | 85% | 0% | 100% | 0% | 100% |
| 2000 | 30% | 70% | 0% | 100% | 0% | 100% |
| 2005 | 35% | 65% | 0% | 100% | 0% | 100% |
| 2010 | 50% | 50% | 100% | 0% | 0% | 100% |
| 2015 | 65% | 35% | 100% | 0% | 0% | 100% |
| 2020 | 100% | 0% | 100% | 0% | 0% | 100% |

| | $LH_2$ | | LPG | | Ethanol | | |
|---|---|---|---|---|---|---|---|
| Year | Central Plants Production | Refueling Stations Production | Crude Feedstock | NG Feedstock | Corn Feedstock | Woody Biomass Feedstock | Herbaceous Biomass Feedstock |
| 1990 | 0% | 100% | 50% | 50% | 100% | 0% | 0% |
| 1995 | 0% | 100% | 45% | 55% | 100% | 0% | 0% |
| 2000 | 0% | 100% | 40% | 60% | 100% | 0% | 0% |
| 2005 | 0% | 100% | 40% | 60% | 100% | 0% | 0% |
| 2010 | 0% | 100% | 40% | 60% | 100% | 0% | 0% |
| 2015 | 0% | 100% | 35% | 65% | 100% | 0% | 0% |
| 2020 | 0% | 100% | 30% | 70% | 100% | 0% | 0% |

**TABLE 3.2 Default Shares of Various Feedstock Sources for $GH_2$ Production in Central Plants**

| Year | NG | Solar: photovoltaic | Nuclear: HTGR-TCWC | Nuclear: HTGR-kWh | Coal | Biomass |
|---|---|---|---|---|---|---|
| 1990 | 100% | 0% | 0% | 0% | 0% | 0% |
| 1995 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2000 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2005 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2010 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2015 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2020 | 100% | 0% | 0% | 0% | 0% | 0% |

**TABLE 3.3 Default Shares of Various Feedstock Sources for $LH_2$ Production in Central Plants**

| Year | NG | Solar: photovoltaic | Nuclear: HTGR-TCWC | Nuclear: HTGR-kWh | Coal | Biomass |
|---|---|---|---|---|---|---|
| 1990 | 100% | 0% | 0% | 0% | 0% | 0% |
| 1995 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2000 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2005 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2010 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2015 | 100% | 0% | 0% | 0% | 0% | 0% |
| 2020 | 100% | 0% | 0% | 0% | 0% | 0% |

**TABLE 3.4 Default Shares of Various Feedstock Sources for $GH_2$ Production at Refueling Stations**

| Year | NG | Electrolysis | EtOH | MeOH |
|---|---|---|---|---|
| 1990 | 100% | 0% | 0% | 0% |
| 1995 | 100% | 0% | 0% | 0% |
| 2000 | 100% | 0% | 0% | 0% |
| 2005 | 100% | 0% | 0% | 0% |
| 2010 | 100% | 0% | 0% | 0% |
| 2015 | 100% | 0% | 0% | 0% |
| 2020 | 100% | 0% | 0% | 0% |

**TABLE 3.5 Default Shares of Various Feedstock Sources for $LH_2$ Production at Refueling Stations**

| Year | NG | Electrolysis | EtOH | MeOH |
|---|---|---|---|---|
| 1990 | 100% | 0% | 0% | 0% |
| 1995 | 100% | 0% | 0% | 0% |
| 2000 | 100% | 0% | 0% | 0% |
| 2005 | 100% | 0% | 0% | 0% |
| 2010 | 100% | 0% | 0% | 0% |
| 2015 | 100% | 0% | 0% | 0% |
| 2020 | 100% | 0% | 0% | 0% |

Even though shares of production options are used in GREET to simulate the effects of a fuel produced from various production options and feedstock sources, you may conduct simulations for a specific fuel production option with a given feedstock exclusive of other possible production options of the same fuel to by assigning 100% market share to that particular production option. In fact, production option-specific results could shed more meaningful light on energy and emission effects of certain production options with certain feedstock for a given fuel. For example, you may select a 100% woody biomass feedstock share for ethanol production to simulate that production pathway exclusive of the corn and herbaceous biomass production pathways of ethanol, so that energy and emission effects of woody cellulosic ethanol can be examined.

## 3.2 Key Simulation Options for Petroleum-Based Fuel Production Pathways

### 3.2.1 Gasoline

For reformulated gasoline, conventional gasoline, and California reformulated gasoline, you can specify the $O_2$ content of each by weight and select the type of oxygenate for blending into gasoline to meet the $O_2$ content requirement as shown in Figures 3.2, 3.3, and 3.4, respectively.

The **types of oxygenate that can be selected for simulation in GREET are:**
- methyl tertiary butyl ether (MTBE)
- ethanol (EtOH)
- ethyl tertiary butyl ether (ETBE)
- tertiary amyl methyl ether (TAME)

However, if you select the “no oxygenate” option, the $O_2$ content is automatically set to zero.

The **vehicle technology options for gasoline use include:**
- spark-ignition (SI) engine
- SI direct-injection (DI) engine
- grid-independent (GI) hybrid electric vehicle (HEV) with SI engine
- grid-connected (GC) HEV with SI engine
- Fuel cell vehicle (FCV) with on-board reforming of gasoline to $H_2$

GREET is intended to simulate the FCV option powered with ultra-low-sulfur gasoline for on-board reforming. But in simulation designs, GREET uses federal RFG or California RFG as the surrogate for ultra-low-sulfur gasoline.

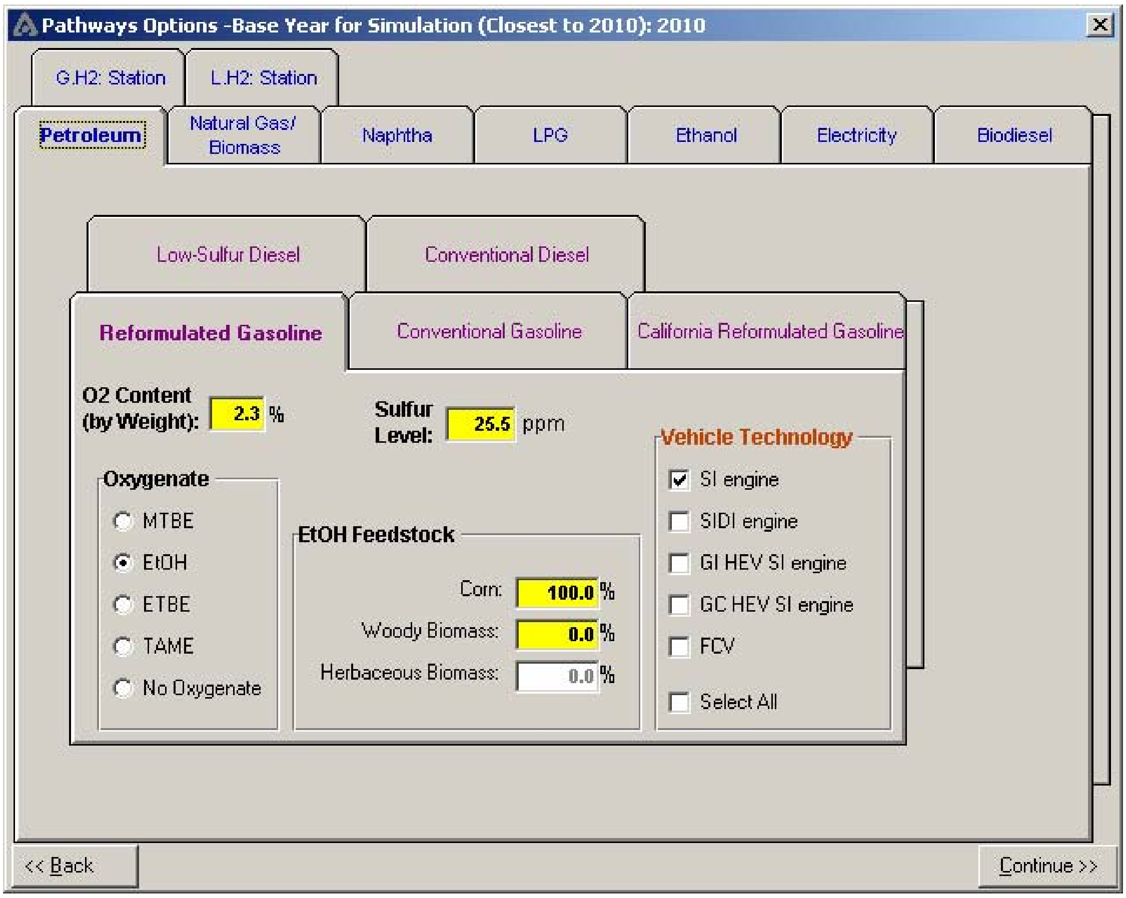


**FIGURE 3.2 Reformulated gasoline production pathway options**

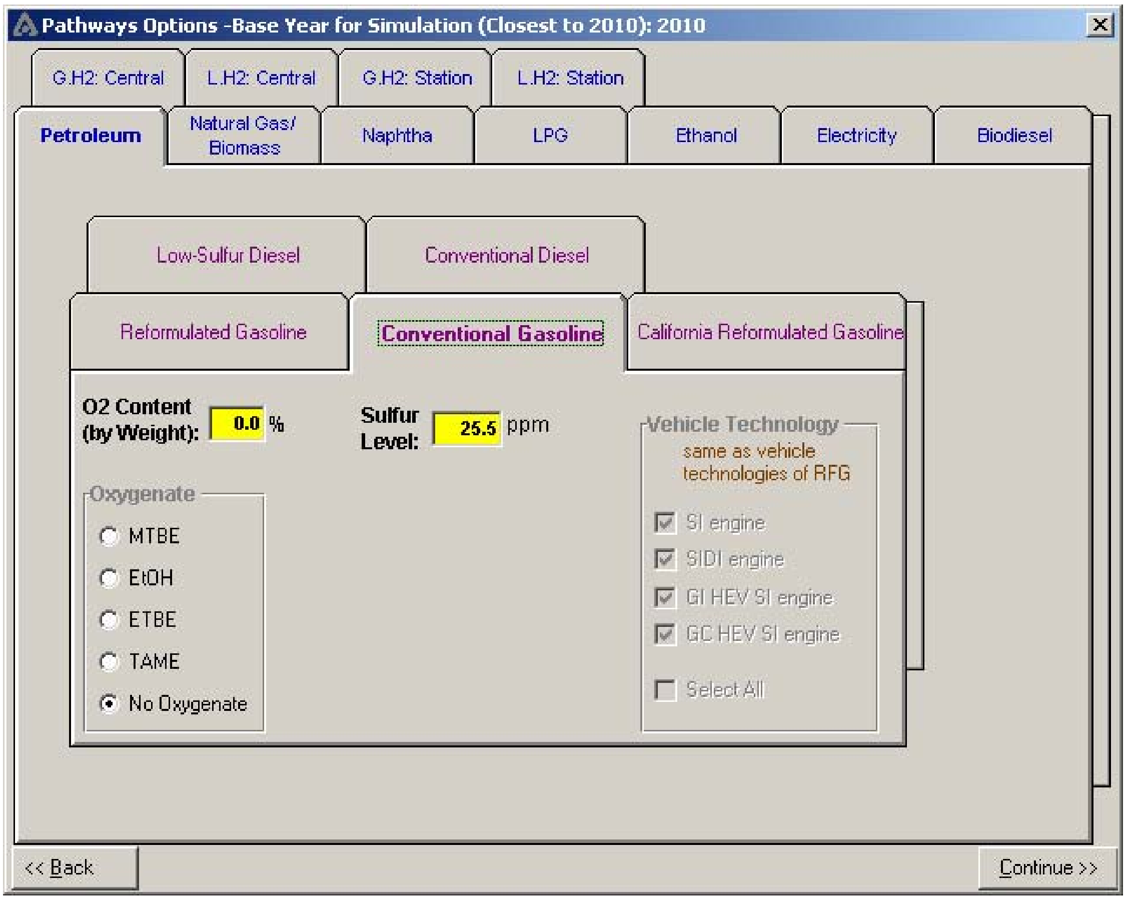


FIGURE 3.3 Conventional gasoline production pathway options

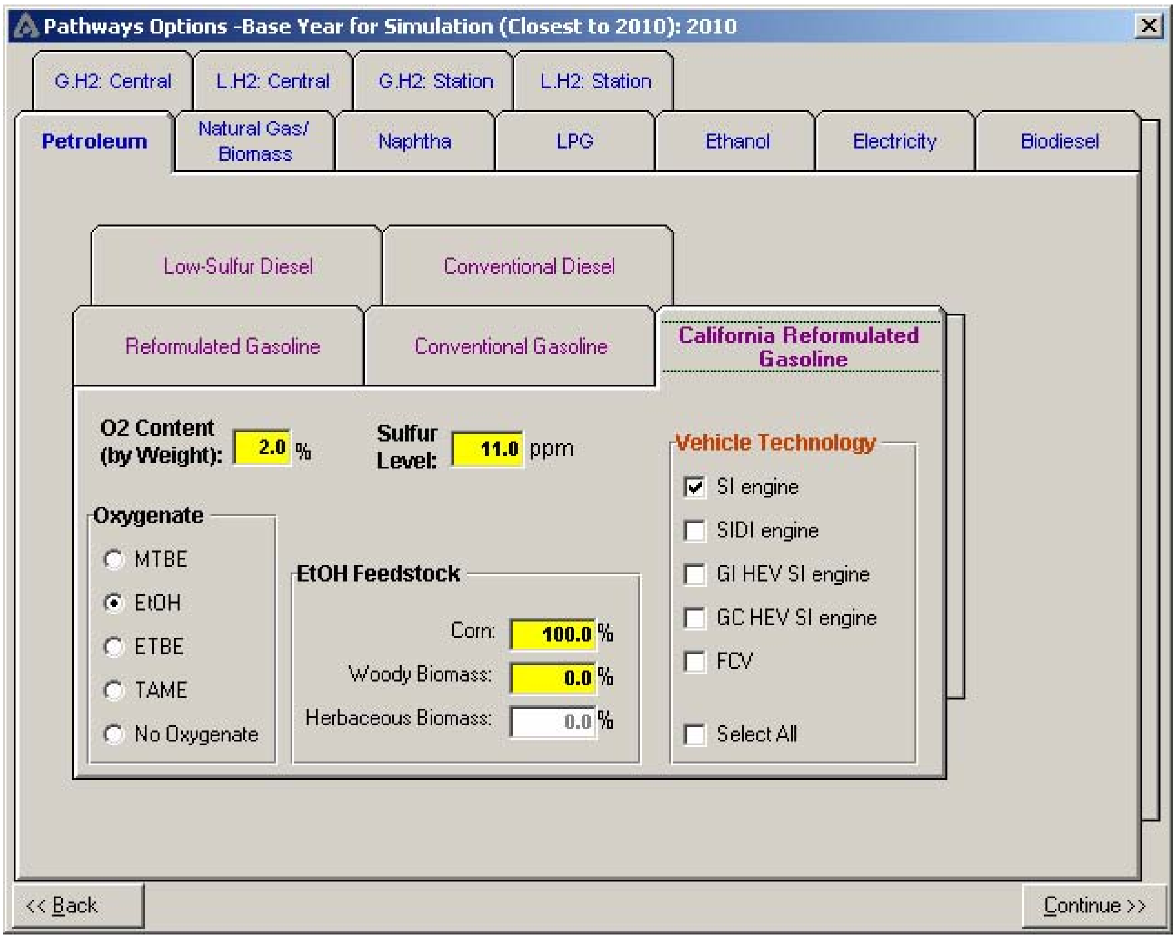


**FIGURE 3.4 California reformulated gasoline production pathway options**

The default sulfur contents in reformulated gasoline and California reformulated gasoline are 26 ppm and 11 ppm, respectively. GREET creates time-series tables for the conventional gasoline sulfur content, as shown in Table 3.6.

**TABLE 3.6 Default Sulfur Contents of Selected Transportation Fuels in ppm**

| Year | CG | CD | California CD | Low-Sulfur Diesel | Non-Road Diesel |
|---|---|---|---|---|---|
| 1990 | 500 | 600 | 350 | NA[a] | 2,283 |
| 1995 | 340 | 350 | 200 | NA[a] | 2,283 |
| 2000 | 200 | 200 | 120 | NA[a] | 2,283 |
| 2005 | 26 | 200 | 120 | NA | 2,283 |
| 2010 | 26 | NA[a] | 120 | 11 | 163 |
| 2015 | 26 | NA[a] | 120 | 11 | 11 |
| 2020 | 26 | NA[a] | 120 | 11 | 11 |

[a]NA – not applicable

In addition to accounting for the differences in the refining efficiencies of the California gasoline and the U.S. gasoline, GREET takes into account the differences in transportation modes and distances from crude oil fields to refineries for both the U.S. in general, and California specifically.

### 3.2.2 Diesel Fuels

For low-sulfur diesel and conventional diesel pathways, you may select the location for diesel use as U.S. or California, as shown in Figures 3.5 and 3.6, respectively. The default location for diesel use in GREET is the entire U.S. If the California location is selected, the transportation mode and distance between crude oil fields and California refineries are used in the simulation for diesel fuels.

The **vehicle technology options for diesel fuels are:**
- compression-ignition (CI) DI engine,
- GI HEV with CIDI engine
- GC HEV with CIDI engine
- FCV with on-board reforming of diesel to $H_2$ — FCV is only available for low-sulfur diesel

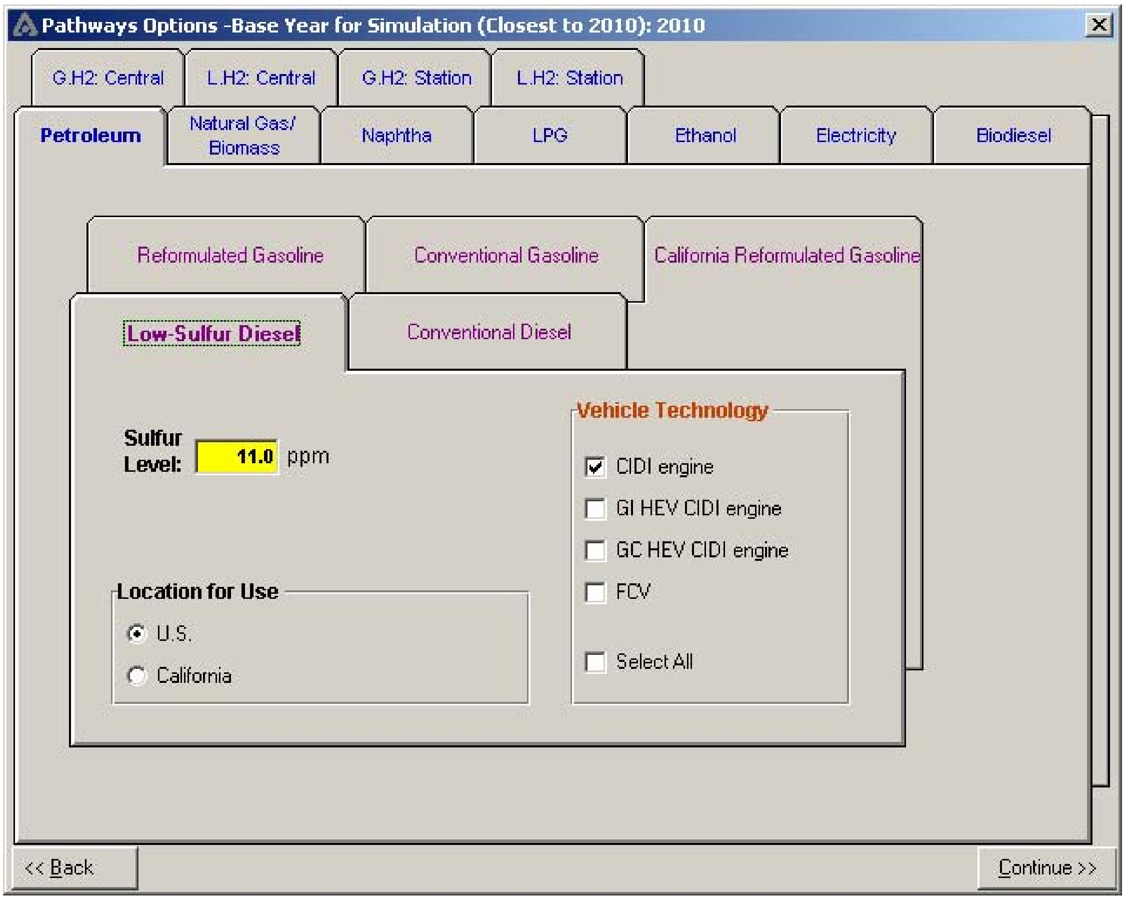


**FIGURE 3.5 Low-sulfur diesel production pathway options**

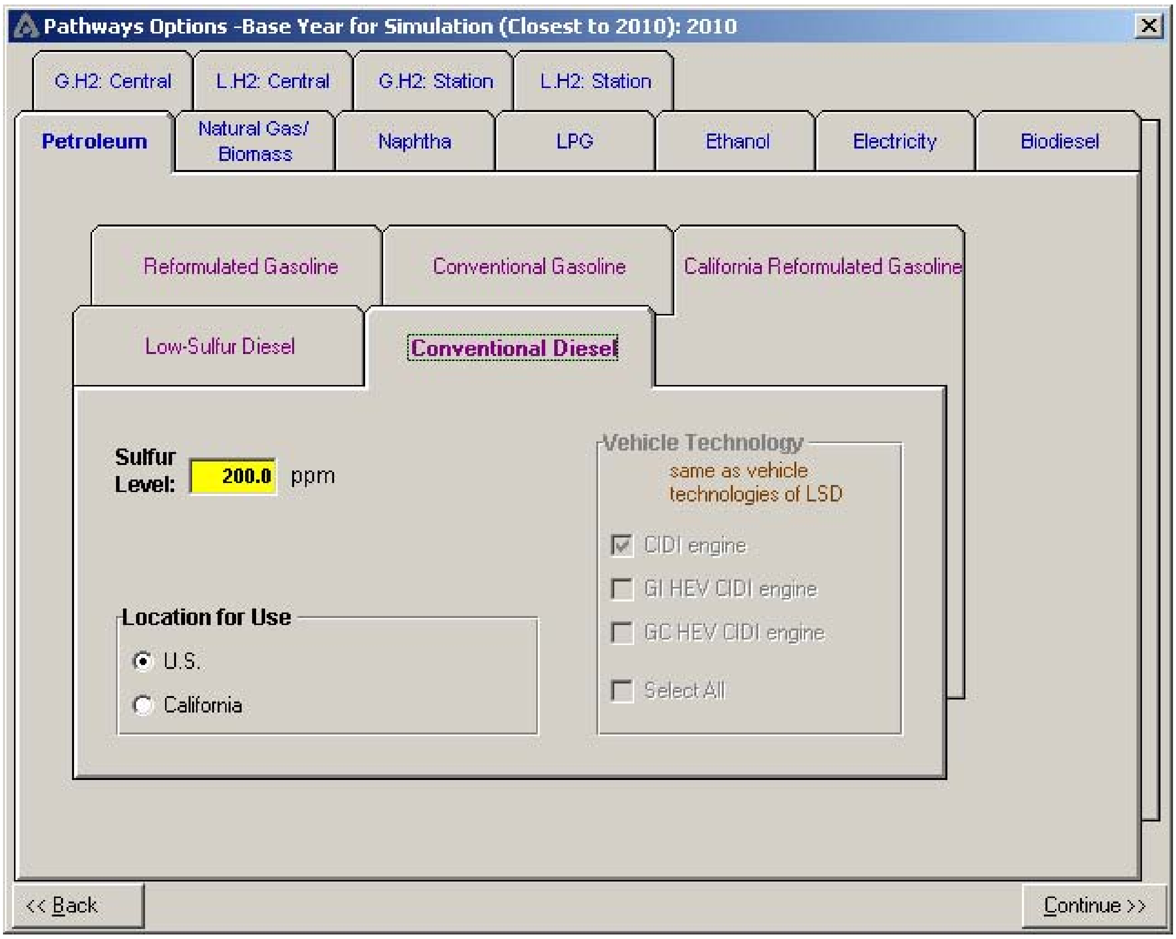


**FIGURE 3.6 Conventional diesel production pathway options**

The default sulfur content in GREET for low-sulfur diesel is 11 ppm, regardless of where it will be used. The sulfur content in conventional diesel is expected to change over time, and therefore, GREET contains time-series tables reflecting the conventional diesel sulfur content (Table 3.6) for U.S. and California locations. Note that the sulfur content for conventional diesel is specified in Table 3.6 only from 1990 to 2005, beyond which the sulfur content of conventional diesel is irrelevant, since its market share is set to zero beyond 2005 as shown in Table 3.1.

## 3.3 Key Simulation Options for NG-Based Pathways

The **NG-based fuels in GREET are:**
- compressed natural gas (CNG)
- liquefied natural gas (LNG)
- methanol (MeOH)
- Fischer-Tropsch Diesel (FTD)
- dimethyl ether (DME)
- naphtha
- liquefied petroleum gas (LPG)
- hydrogen ($H_2$)

Natural gas-based naphtha, LPG, and $H_2$ production pathways are discussed separately in sections 3.4, 3.5, and 3.10 through 3.13, respectively.

### 3.3.1 CNG

As shown in Figure 3.7, the **three feedstock source options for CNG include:**
- North American (NA) natural gas
- non-North American (NNA) natural gas
- non-North American flared gas (FG)

For the non-North America feedstock sources to CNG, the feedstock gas is converted into LNG for transportation to North America, where it is gasified at the LNG receiving terminal. The GREET default simulation option for CNG feedstock source is the North America natural gas.

The **vehicle technology options for CNG are:**
- bi-fuel SI engine
- dedicated SI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV with on-board reforming of NG to $H_2$

### 3.3.2 LNG

As shown in Figure 3.8, the **three feedstock source options for LNG include:**
- North American natural gas
- non-North American natural gas
- non-North American flared gas

The GREET default simulation option for LNG feedstock source is North America natural gas.

The **vehicle technology options for LNG are:**

- dedicated SI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV with on-board reforming of NG to $H_2$

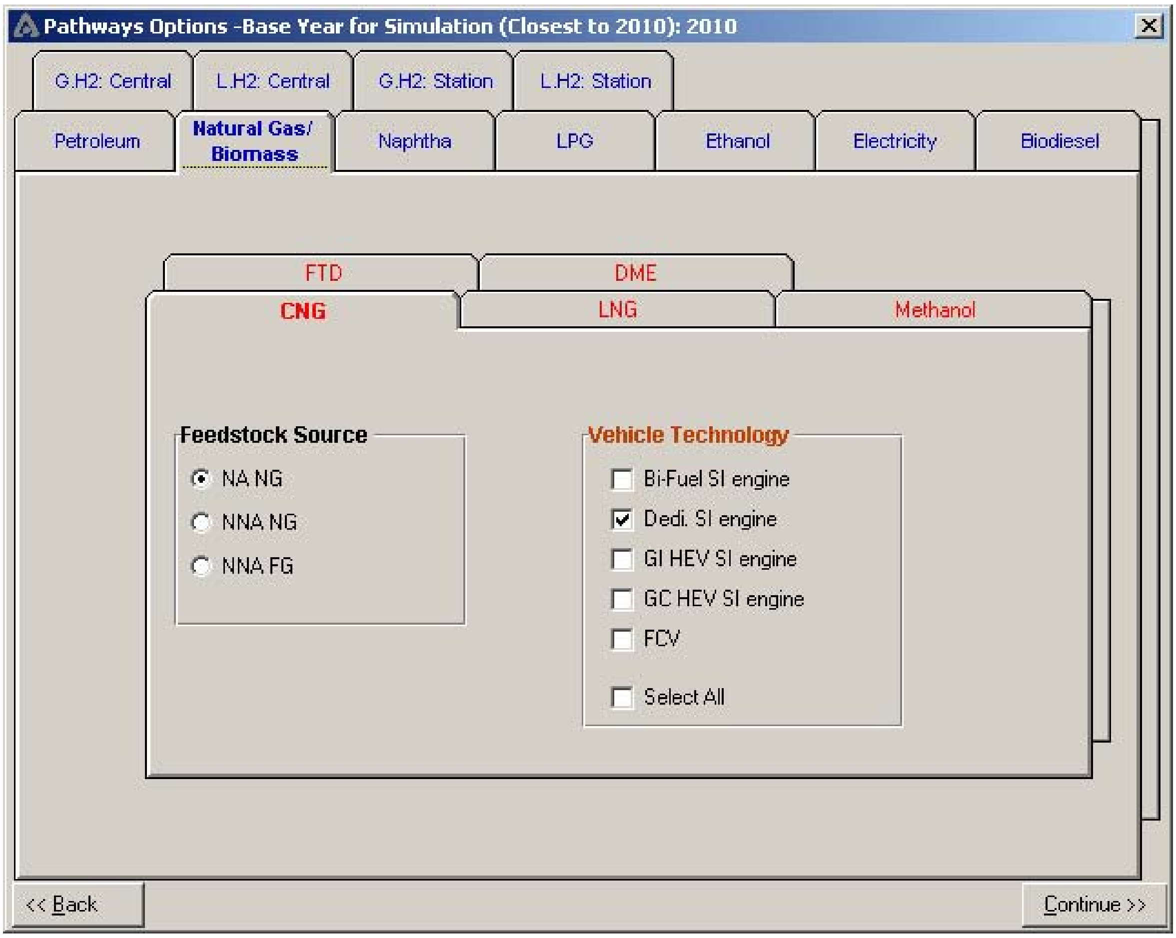


**FIGURE 3.7 CNG production pathway options**

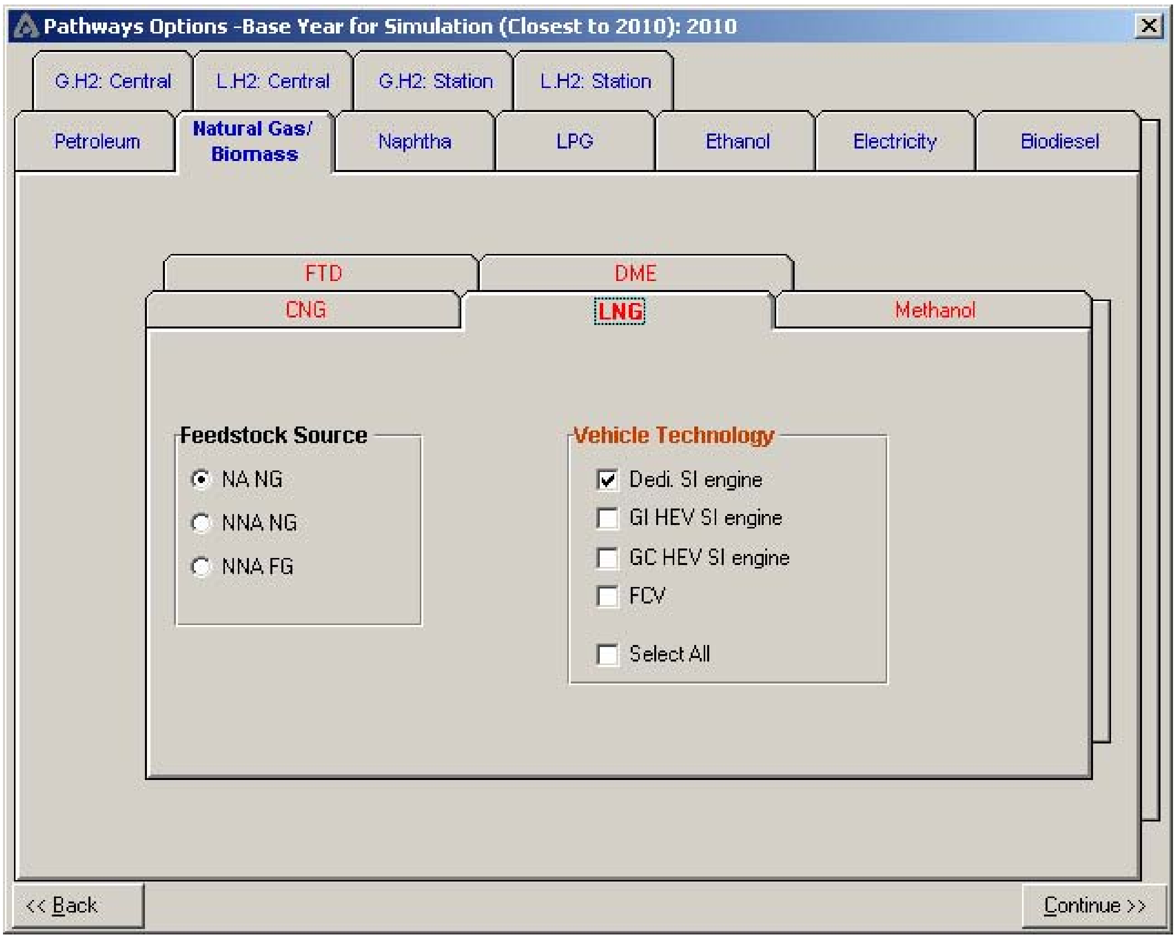


**FIGURE 3.8 LNG production pathway options**

### 3.3.3 FTD

As shown in Figure 3.9, the **three feedstock source options for FTD production include:**

- North American natural gas
- non-North American natural gas
- non-North American flared gas

In addition to the above three NG-based feedstock sources, you may choose biomass as a fourth feedstock option, which is discussed separately in section 3.6.

The **plant design types for FTD production include:**

- standalone plant design without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The credits for FTD production are discussed in section 4.2.6.

Currently, all announced FTD plants are located outside of North America, mainly due to the availability of inexpensive NG outside of North America. Therefore, the default feedstock source for FTD production is non-North American NG and the default plant design type is without steam or electricity export, as shown in Figure 3.9.

The **vehicle technology options for FTD are:**

- CIDI engine
- GI HEV with CIDI engine
- GC HEV with CIDI engine

In addition, FTD can be blended with petroleum diesel for vehicle applications.

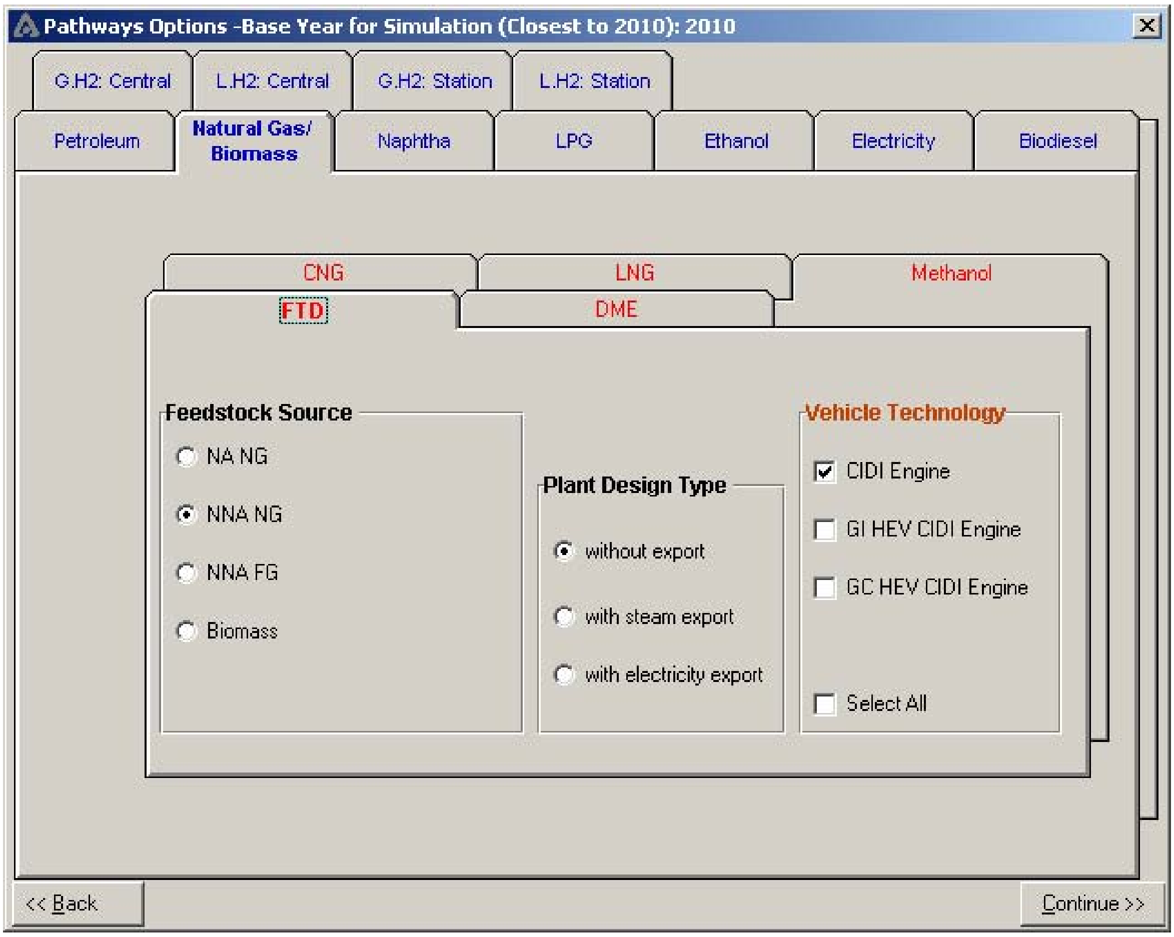


**FIGURE 3.9 FTD production pathway options (NG as Feedstock)**

### 3.3.4 Methanol

As shown in Figure 3.10, **the three feedstock source options for methanol include:**
- North American natural gas
- non-North American natural gas
- non-North American flared gas

In addition to the above three NG-based feedstock sources, you can also choose landfill gas and biomass as feedstock source options. The biomass-based methanol pathway is discussed separately in section 3.6.

The **plant design types for methanol production include:**
- without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The credits for methanol production are discussed in section 4.2.5.

Due to inexpensive NG outside of North America, most methanol plants are located outside of North America. Therefore, the default feedstock source for methanol production is non-North American NG, and the default plant design type is without steam or electricity export, as shown in Figure 3.10.

The **vehicle technology options for methanol are:**
- flexible-fuel vehicle (FFV) with SI engine
- dedicated SI engine
- SIDI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV with on-board reforming of methanol to $H_2$. Except for FCV, methanol is blended with gasoline for vehicle applications

### 3.3.5 DME

As shown in Figure 3.11, the **feedstock source options for DME include:**
- North American natural gas
- non-North American natural gas
- non-North American flared gas

In addition to the above three NG-based feedstock sources, you can also choose biomass as a fourth feedstock option; this is discussed separately in section 3.6.

The **plant design types for DME production include:**

- without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The credits for DME production are discussed in section 4.2.7.

The default feedstock source for DME production is non-North America NG because inexpensive NG is available there. The default plant design type is without steam or electricity export, as shown in Figure 3.11.

The **vehicle technology options for DME are:**

- CIDI engine
- GI HEV with CIDI engine
- GC HEV with CIDI engine

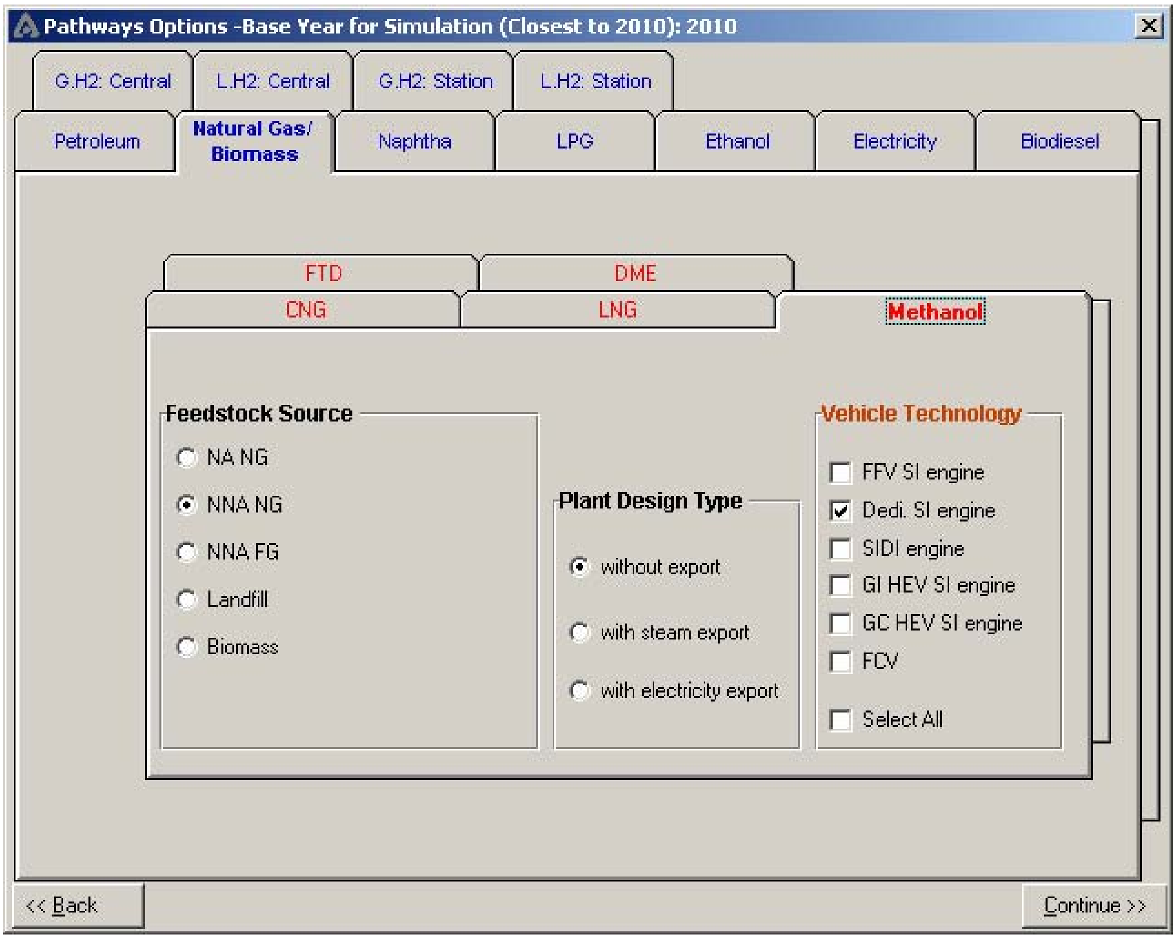


**FIGURE 3.10 Methanol production pathway options (NG as feedstock)**

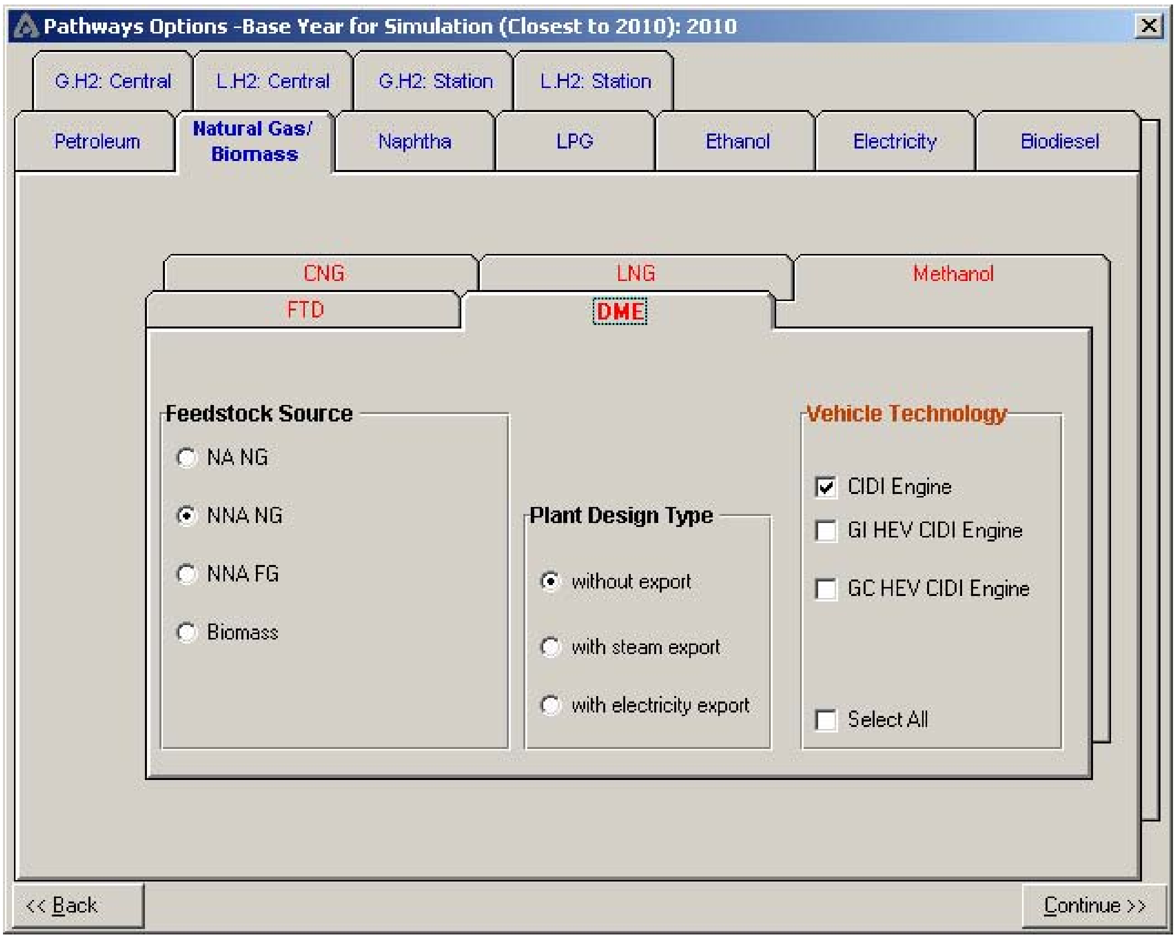


**FIGURE 3.11 DME production pathway options (NG as feedstock)**

## 3.4 Key Simulation Options for Naphtha Production Pathways

The feedstock sources for naphtha production are NG and crude oil. The GREET model allows you to select the market shares of the NG and crude oil feedstock sources as shown in Figure 3.12. The default feedstock market share for naphtha is 100% of NG in FTD plants where naphtha is a co-product with FTD.

For the NG-based naphtha production pathway, you can select **the feedstock source for naphtha production as:**

- North American NG
- non-North American NG
- non-North American FG

The **FTD plant design types for NG-based naphtha production include:**

- without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The credits for naphtha production are discussed in section 4.2.8.

All announced FTD plants so far are located outside of North America. Therefore, the default feedstock source for naphtha production is non-North America NG and the default plant design type is without steam or electricity export, as shown in Figure 3.12.

If you select petroleum-based naphtha, you can also select the location for naphtha use as U.S. or California. The default location for naphtha use is the entire U.S. If the California location is selected, the transportation mode and distance for transporting crude oil to California refineries are used in the simulation.

The default sulfur content for petroleum-based naphtha is 1 ppm, regardless of its location for use.

FCV is the only vehicle technology option available for naphtha in GREET. Naphtha is reformed on-board FCVs to produce $H_2$.

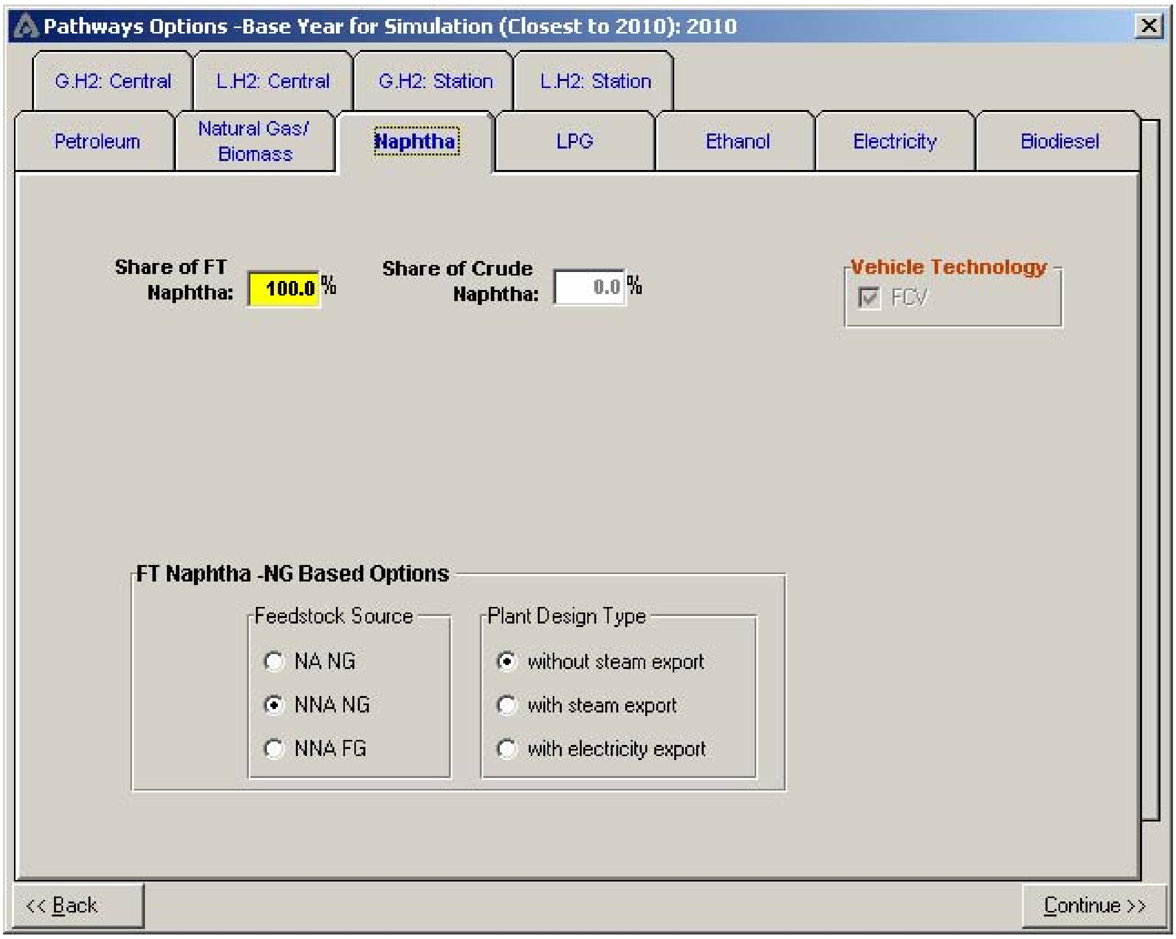


**FIGURE 3.12 Naphtha production pathway options**

## 3.5 Key Simulation Options for LPG Production Pathways

LPG can be produced from crude oil at petroleum refineries and NG at NG processing plants. The GREET model allows you to select the market shares of the crude oil and NG feedstock sources as explained in section 3.1 above.

As shown in Figure 3.13, **for the NG-based LPG production pathway, you can select the feedstock source for LPG production as:**

- North American NG
- non-North American NG

The default feedstock source for LPG production is North American NG.

The **vehicle technology options for LPG are:**

- dedicated SI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV with on-board reforming of LPG to $H_2$

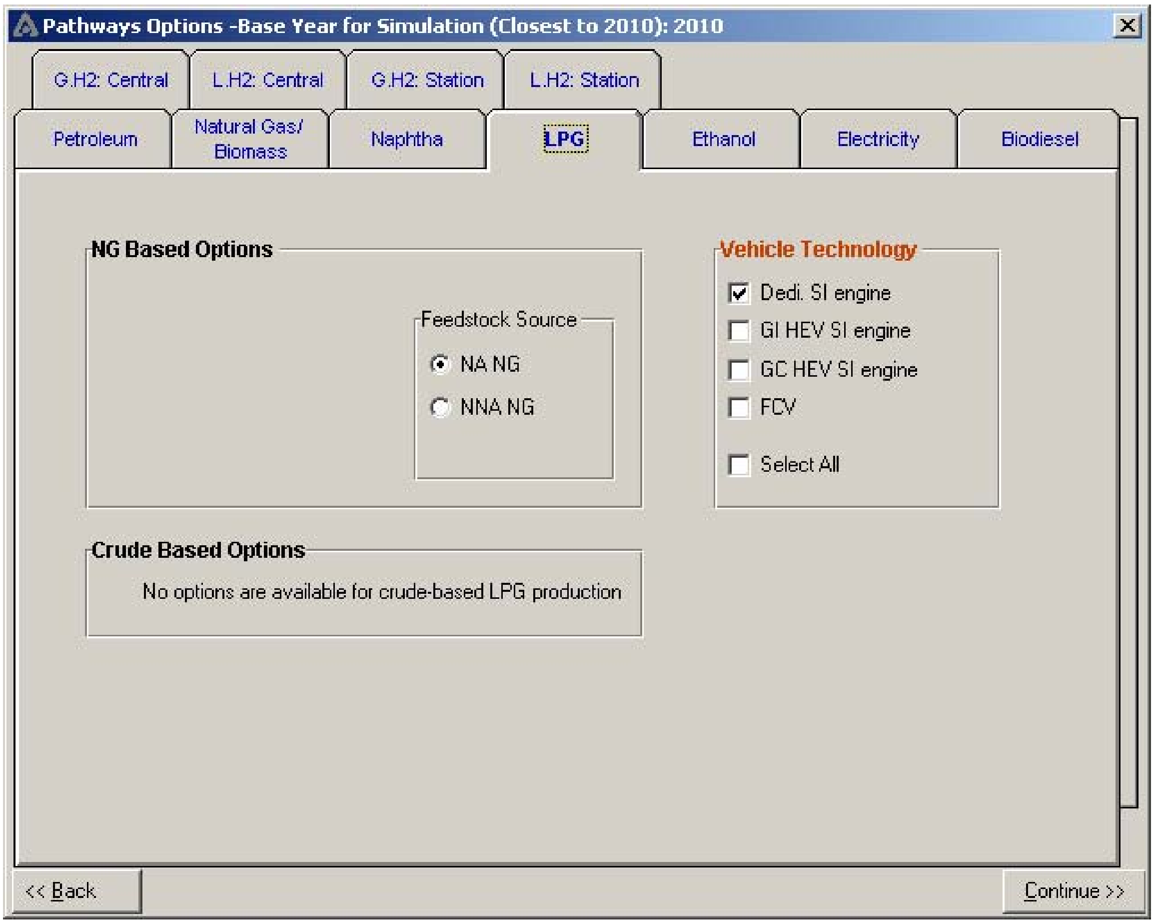


**FIGURE 3.13 LPG production pathway options**

## 3.6 Key Simulation Options for Biomass-Based Fuel Pathways

The **biomass-based fuels in GREET are:**

- MeOH
- FTD
- DME
- EtOH
- $H_2$

Biomass-based EtOH and $H_2$ production pathways are discussed separately in sections 3.7 and 3.10 through 3.13, respectively.

### 3.6.1 Methanol

Methanol can be produced from woody biomass and herbaceous biomass via gasification. The GREET model allows you to select the market shares of the woody and herbaceous biomass feedstock sources, as shown in Figure 3.14. The default feedstock market share for methanol production is 100% herbaceous biomass.

**The plant design types for biomass-based methanol production include:**

- without electricity export
- with electricity export

For the latter option, the energy and emission credits from the co-generated electricity are automatically estimated in GREET.

Note that currently, this pathway is just a placeholder in the GREET model, i.e., the model structure is completely in place for this specific fuel pathway, but the parameter values are uncertain. Therefore, you should exercise caution when using the GREET default numbers. Efforts are underway to search for reliable data in publicly available sources.

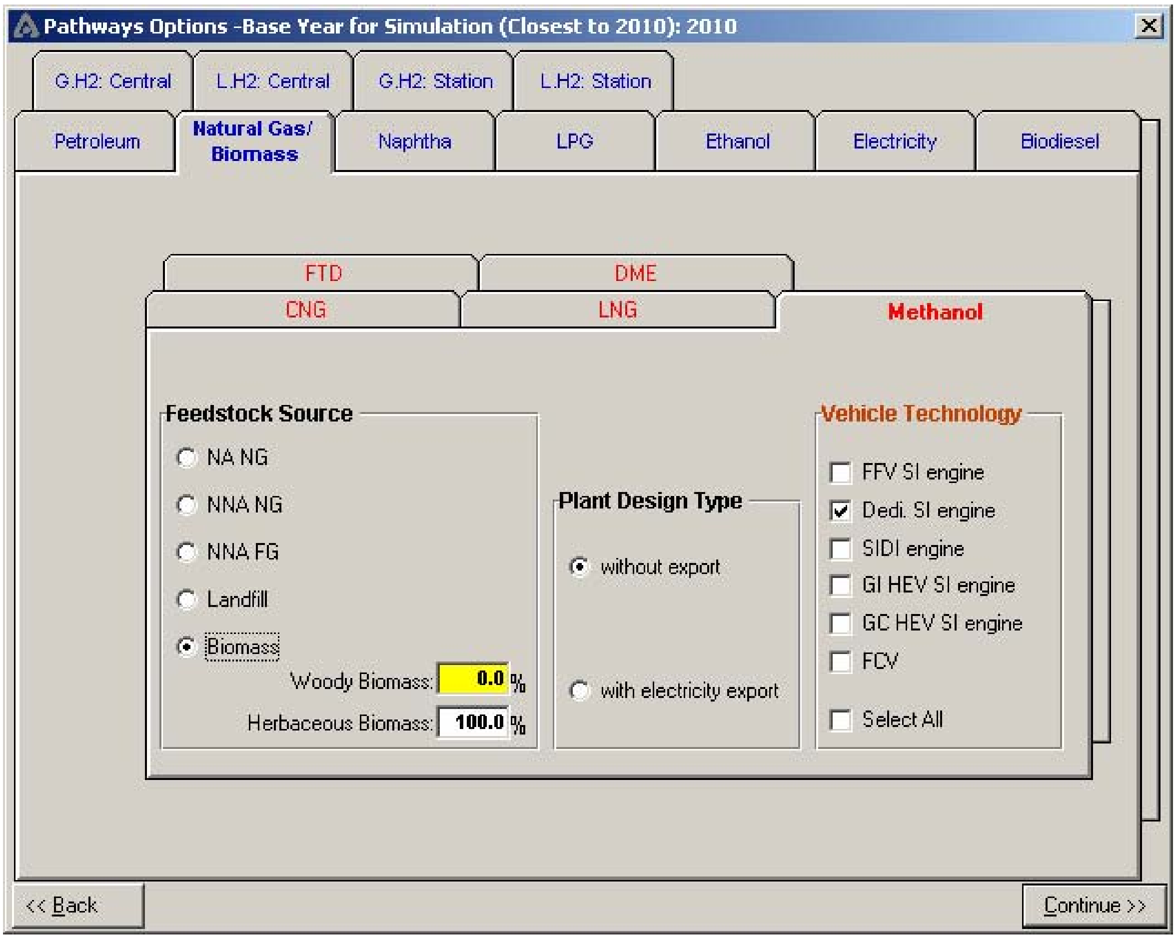


**FIGURE 3.14 Methanol production pathway options (biomass as feedstock)**

### 3.6.2 FTD

FTD can be produced from woody biomass and herbaceous biomass via gasification. The GREET model allows you to select the market shares of the woody and herbaceous biomass feedstock sources, as shown in Figure 3.15. The default feedstock market share for FTD production is 100% of herbaceous biomass.

The **plant design types for biomass-based FTD production include:**

- without electricity export
- with electricity export

For the latter option, the energy and emission credits from the co-generated electricity are automatically estimated in GREET.

Note that studies on biomass gasification for FTD production are very limited. The default data in GREET are based on a study conducted for *The Role of Biomass in America's Energy Future* (for details, see Wu et al. 2005). In that study, only one production scenario, biomass-based FTD with electricity co-generation via gas turbine combined cycle (GTCC), was simulated. Electricity was no longer a by-product, but a major energy co-product. Two methods, the allocation method and the displacement method, were applied for electricity credit partition.

In this version of GREET, data that were generated through the RBAEF project were processed for applications to the plant designs without electricity export, while the displacement method was applied for the second design option (with electricity export). Therefore, you should exercise caution when simulating this fuel pathway.

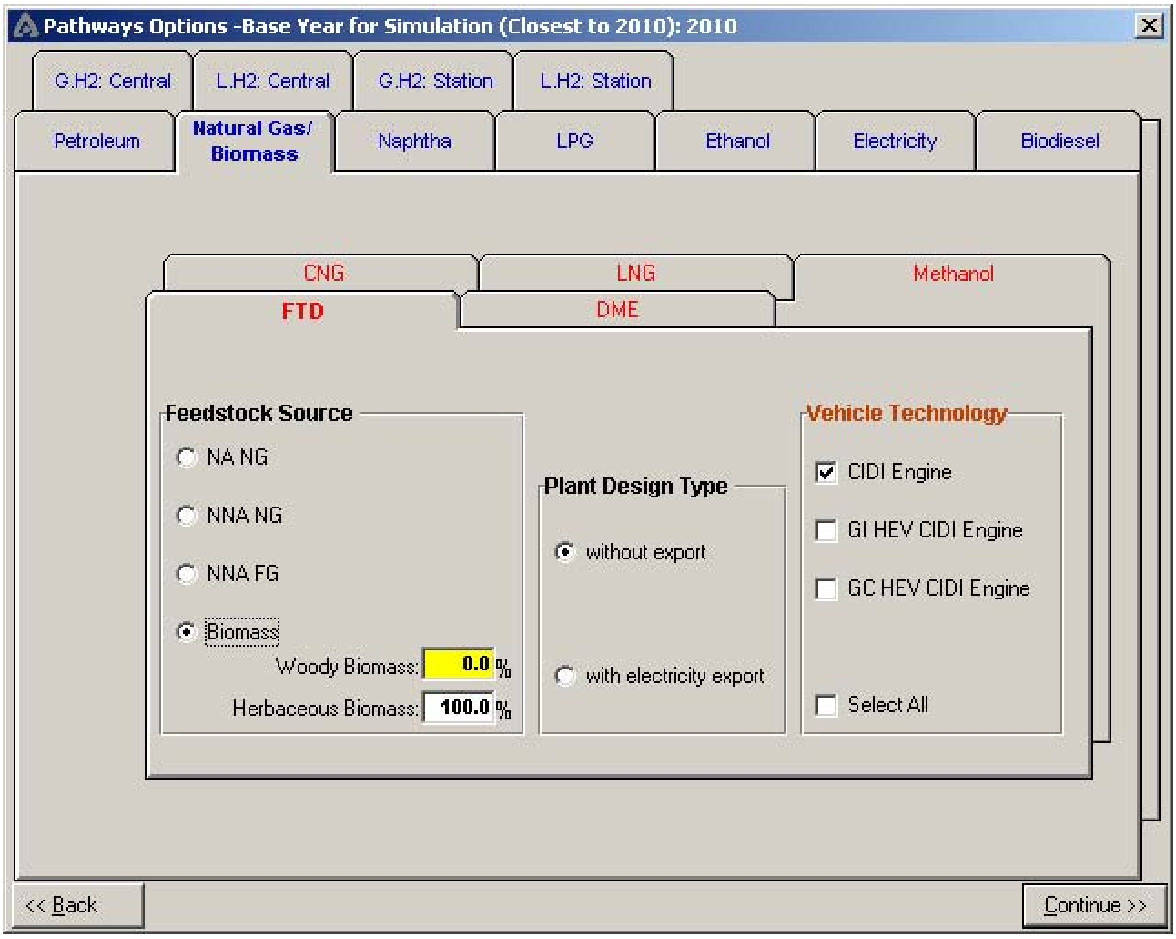


**FIGURE 3.15 FTD production pathway options (biomass as feedstock)**

### 3.6.3 DME

DME can be produced from woody biomass and herbaceous biomass via gasification. The GREET model allows you to select the market shares of the woody and herbaceous biomass feedstock sources, as shown in Figure 3.16. The default feedstock market share for DME production is 100% of herbaceous biomass.

The **plant design types for biomass-based DME production include:**

- without electricity export
- with electricity export

For the latter option, the energy and emission credits from the co-generated electricity are automatically estimated in GREET.

Note that available data for this pathway are very limited. The default data in GREET are based on a study conducted for *The Role of Biomass in America's Energy Future* (RBAEF) (for details, see Wu et al. 2005). In that study, only one production scenario, biomass-based DME with electricity co-generation via gas turbine combined cycle (GTCC), was simulated. Electricity was no longer a by-product, but a major energy co-product. Two methods, the allocation method and the displacement method, were applied for electricity credit partition.

In this version of GREET, data that were generated through the RBAEF project were processed for applications to the plant designs without electricity export, while the displacement method was applied for the second design option (with electricity export). Therefore, you should exercise caution when simulating this fuel pathway.

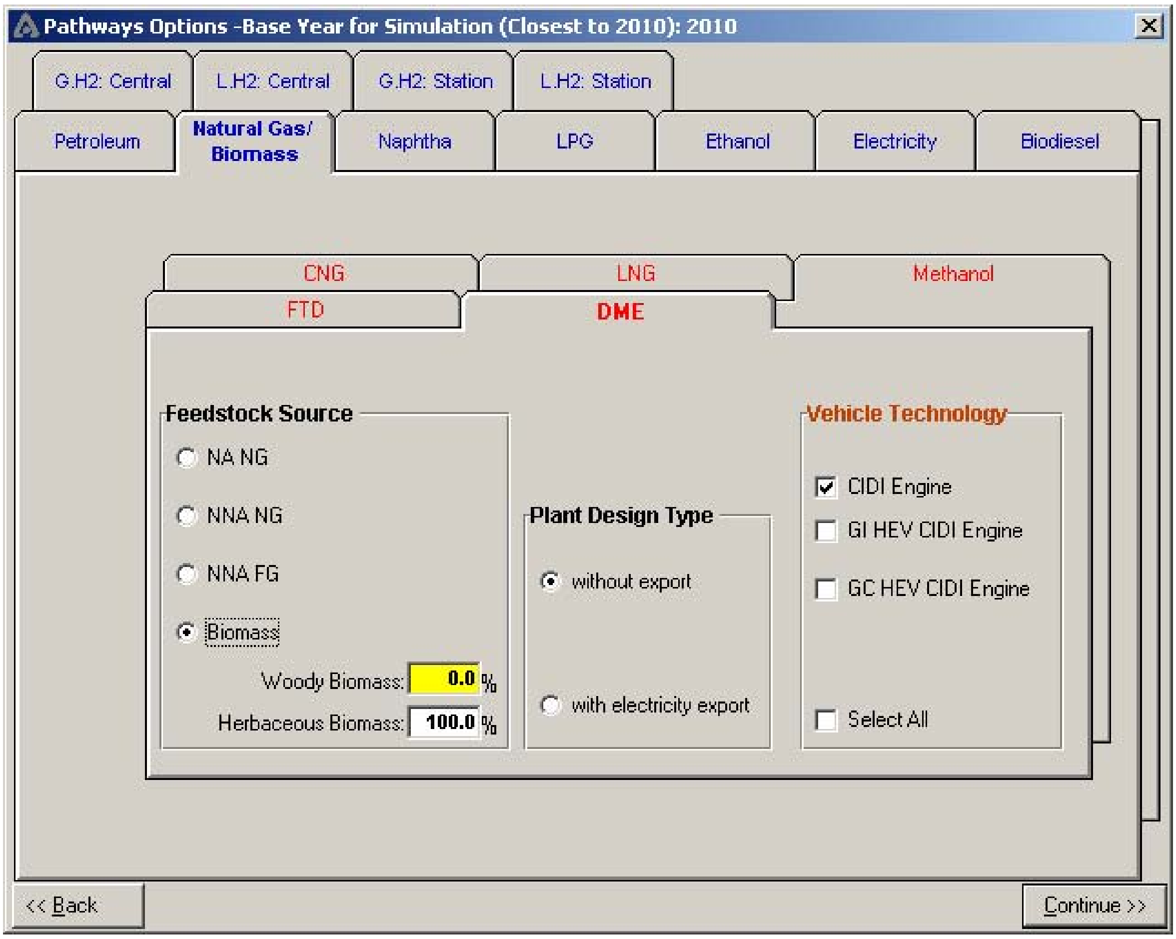


**FIGURE 3.16 DME production pathway options (biomass as feedstock)**

## 3.7 Key Simulation Options for Ethanol Production Pathways

As shown in section 3.1, **ethanol can be produced from:**

- corn
- woody biomass
- herbaceous biomass

As shown in Figure 3.17, the **plant design options for the corn-to-ethanol pathway include:**

- dry milling plants (DMP)
- wet milling plants (WMP)

Wet milling plants produce ethanol from cornstarch. Other co-products in wet milling plants include high-fructose corn syrup, glucose, gluten feed, and gluten meal. Dry milling plants, which are smaller than wet milling plants, are designed primarily for ethanol production. In dry milling plants, ethanol is produced from cornstarch, while other constituents of the corn kernel end up in distillers' dried grains and solubles (DDGS). The shares of ethanol production from dry milling and wet milling plants may change over time. In the U.S., dry milling plants market share has increased significantly since 1990s. Therefore, time-series tables for the shares of the two plant types (dry milling vs. wet milling) have been developed in GREET, see Table 3.7.

Process fuels used for dry milling plants and wet milling plants are typically NG and coal. The share of process fuels for each plant type may also change over time. Time-series tables for the default shares of process fuels for each plant type were developed in GREET, as shown in Table 3.7.

In addition to ethanol production, corn-based ethanol plants produce a variety of co-products as mentioned above. GREET allocates emissions and energy use charge between ethanol and its co-products by using either a product displacement method or a market value-based method. The default method in GREET is the product displacement method.

Because of the differences in the fuel types to which ethanol is blended and the ethanol blending level, the vehicle technology options for ethanol are divided into the following four categories.

**High blending levels of ethanol with gasoline (e.g., E85)**
Vehicle technologies include:
- FFV SI engine
- dedicated SI engine
- SIDI engine
- GI HEV with SI engine
- GC HEV with SI engine

**Low blending levels of ethanol with gasoline (e.g., E10)**
Vehicle technologies include:
- SI engine
- SIDI engine
- GI HEV with SI engine
- GC HEV with SI engine

**Low blending levels of ethanol with diesel (e.g., ED10)**
Vehicle technologies include:
- CIDI engine
- GI HEV with CIDI engine
- GC HEV with CIDI engine

**FCV for pure ethanol with on-board reforming of ethanol to $H_2$**

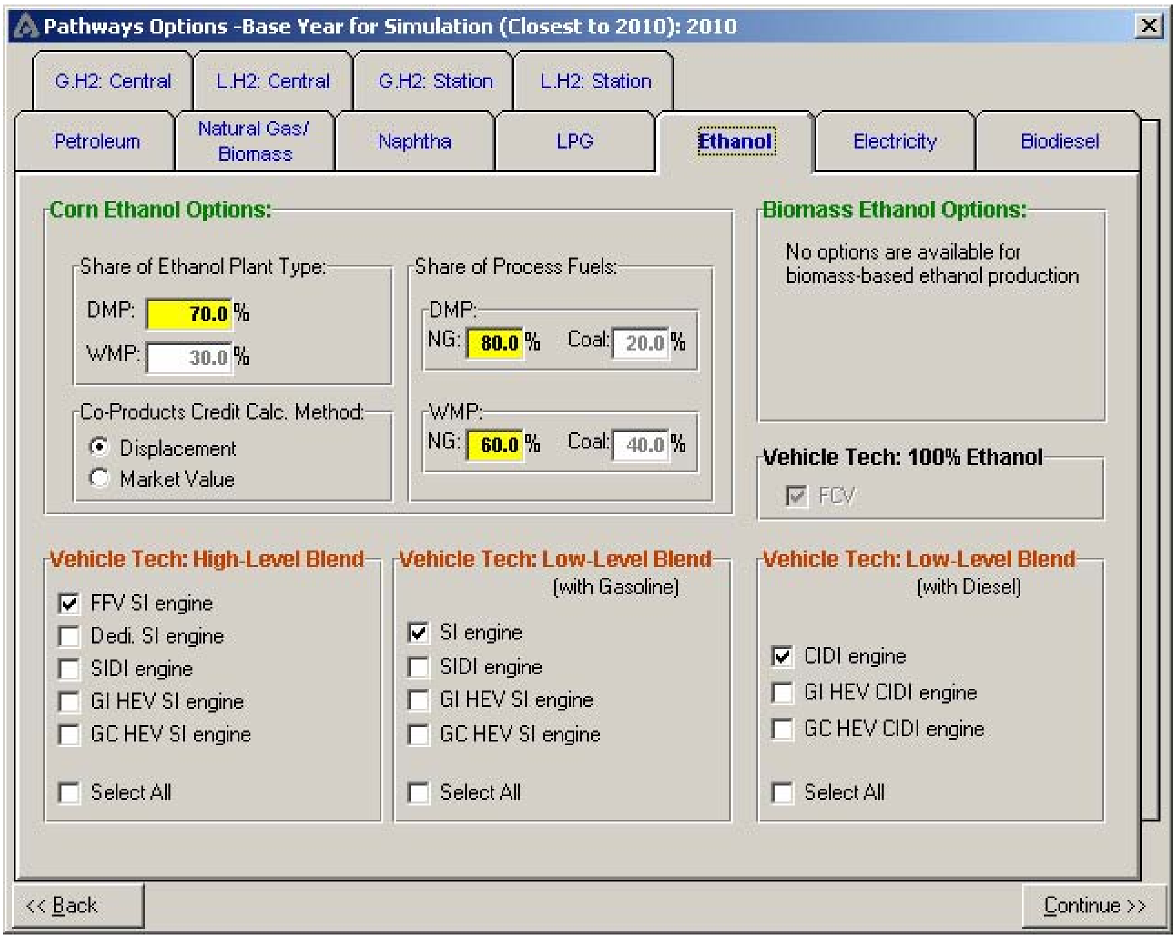


**FIGURE 3.17 Ethanol production pathway options**

**TABLE 3.7 Default Shares of Plant Types and Process Fuels for Corn-Ethanol Plants**

| Year | Share of corn-ethanol plant type | | Share of process fuels for DMP | | Share of process fuels for WMP | |
|---|---|---|---|---|---|---|
| | DMP | WMP | Coal | NG | Coal | NG |
| 1990 | 30% | 70% | 40% | 60% | 50% | 50% |
| 1995 | 33% | 67% | 35% | 65% | 50% | 50% |
| 2000 | 67% | 33% | 30% | 70% | 40% | 60% |
| 2005 | 68% | 32% | 20% | 80% | 40% | 60% |
| 2010 | 70% | 30% | 20% | 80% | 40% | 60% |
| 2015 | 75% | 30% | 20% | 80% | 40% | 60% |
| 2020 | 80% | 30% | 20% | 80% | 40% | 60% |

## 3.8 Key Simulation Options for Electricity Generation

Energy use and emissions of electricity generation are needed in GREET for two purposes: (1) electricity usage in well-to-pump (WTP) activities, and (2) electricity use in electric vehicles (EVs), grid-connected HEVs, and $H_2$ FCVs with electrolysis.

The GREET model calculates emissions associated with electricity generation from residual oil, NG, coal, biomass, and uranium feedstock sources. Of the various power plant types, those fueled by residual oil, NG, coal, and biomass produce emissions at the plant site, besides emissions associated with production and delivery of the fuels to power plants.

Although nuclear power plants do not produce air emissions at the plant site, emissions and energy use associated with the upstream production of uranium and its preparation stages are accounted for in GREET. Electricity generated from hydropower, solar, wind, and geothermal sources are treated as zero-emission plants in GREET; and are categorized together in one group named “Others.” GREET does not include estimation of emissions associated with construction of facilities.

GREET has two sets of electricity generation mix: 1) marginal generation mix for transportation use, which is used for EVs, grid-connected HEVs and FCVs with $H_2$ production via electrolysis at refueling stations; and 2) average generation mix, which is used in all WTP activities.

**You can select an electricity generation mix from one of the following options:**
- U.S. average electricity mix
- North-Eastern U.S. average electricity mix
- California electricity mix
- user-defined mix

Table 3.8 lists the default electricity generation mix over time in GREET. Future trends (2005-2020) for U.S. average electricity mix, North-Eastern U.S. average electricity, and California electricity mix are based on projections from Energy Information Administration (EIA).

GREET default simulations assume that marginal electric generation mixes for transportation applications are the same as average generation mixes, since marginal mix data is not available.

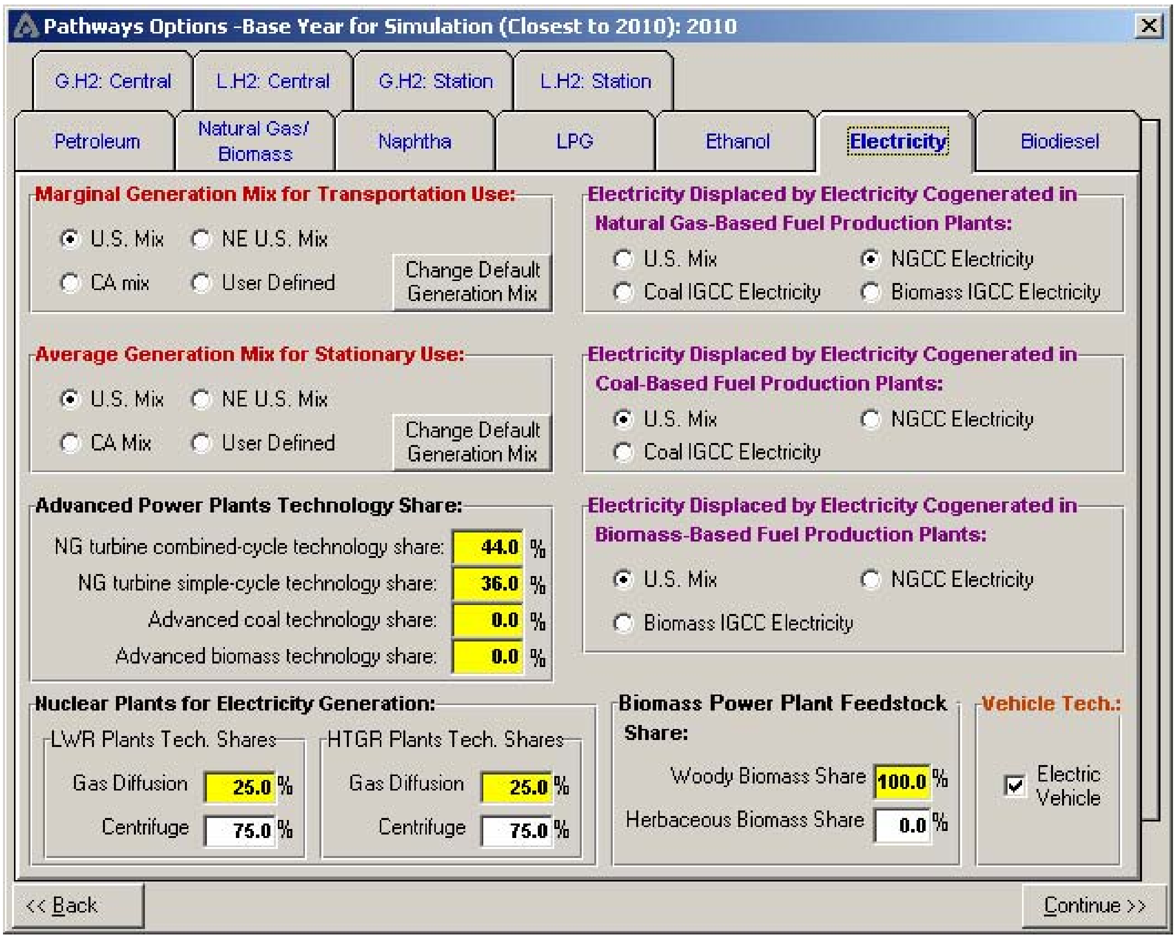


**FIGURE 3.18 Electricity generation options**

**TABLE 3.8 Default Electricity Generation Mix**

| U.S. mix | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Power Plant types** | | | | | |
| | **Residual Oil** | **NG** | **Coal** | **Nuclear** | **Biomass** | **Others** |
| 1990 | 4.2% | 12.3% | 52.5% | 19.0% | 1.1% | 10.9% |
| 1995 | 2.2% | 14.8% | 51.0% | 20.1% | 1.2% | 10.7% |
| 2000 | 2.9% | 15.8% | 51.7% | 19.8% | 1.1% | 8.7% |
| 2005 | 2.9% | 15.7% | 51.7% | 20.3% | 1.2% | 8.2% |
| 2010 | 2.7% | 18.9% | 50.7% | 18.7% | 1.3% | 7.7% |
| 2015 | 2.6% | 22.5% | 48.7% | 17.6% | 1.3% | 7.3% |
| 2020 | 2.6% | 24.3% | 48.6% | 16.3% | 1.4% | 6.8% |

**TABLE 3.8 Default Electricity Generation Mix (Cont.)**

| Northeast U.S. mix | | | | | | |
|---|---|---|---|---|---|---|
| | Power Plant types | | | | | |
| Year | Residual Oil | NG | Coal | Nuclear | Biomass | Others |
| 1990 | 15.1% | 8.6% | 37.2% | 28.7% | 2.4% | 8.0% |
| 1995 | 5.6% | 18.9% | 35.6% | 30.2% | 2.3% | 7.4% |
| 2000 | 7.4% | 15.2% | 35.9% | 32.0% | 2.3% | 7.2% |
| 2005 | 7.4% | 17.9% | 31.6% | 33.4% | 3.4% | 6.3% |
| 2010 | 6.6% | 20.9% | 32.2% | 31.0% | 3.6% | 5.7% |
| 2015 | 6.4% | 24.6% | 31.0% | 29.2% | 3.8% | 5.0% |
| 2020 | 6.9% | 27.6% | 29.5% | 27.5% | 3.8% | 4.7% |
| **California mix** | | | | | | |
| | **Power Plant types** | | | | | |
| **Year** | **Residual Oil** | **NG** | **Coal** | **Nuclear** | **Biomass** | **Others** |
| 1990 | 2.3% | 40.0% | 11.2% | 19.2% | 1.4% | 25.9% |
| 1995 | 0.2% | 37.5% | 8.6% | 17.3% | 1.4% | 35.0% |
| 2000 | 0.2% | 42.1% | 14.5% | 17.1% | 1.4% | 24.7% |
| 2005 | 0.8% | 35.2% | 15.9% | 21.5% | 1.6% | 25.0% |
| 2010 | 0.7% | 41.5% | 14.6% | 18.9% | 1.7% | 22.6% |
| 2015 | 0.6% | 42.0% | 21.0% | 15.6% | 1.5% | 19.3% |
| 2020 | 0.7% | 36.0% | 31.4% | 13.5% | 1.5% | 16.9% |

The GREET model includes two types of nuclear reactor technologies for electricity generation, the conventional light water reactor (LWR) and the HTGR. You can select the technology shares of uranium enrichment for each type of the nuclear reactors. The technologies used for uranium enrichment include gaseous diffusion and centrifuge enrichment. The market share of these two enrichment technologies may change over time. Table 3.9 shows the time-series tables for the GREET default shares of gaseous diffusion and centrifuge technologies used for uranium enrichment. Note that electricity consumption for uranium enrichment in gaseous diffusion plants is nearly 50 times higher than that in centrifuge plants (see section 4.5.3).

The GREET model provides the market share of biomass power plant feedstock source (see Figure 3.18). The default feedstock market share is 100% woody biomass.

Some advanced technologies for electricity generation, such as NG combined-cycle (NGCC) for NG power plants and integrated gasification combined-cycle (IGCC) for coal power plants, could increase their shares of electricity generation over time. The time-series tables for the default shares of these generation technologies used in NG power plants, coal power plants and biomass power plants in GREET are shown in Table 3.10. Future trends of market shares (2005–2020) for these generation technologies (except for biomass power plants) are based on projections from the U.S. Department of Energy, Energy Information Administration (EIA). Advanced technology shares for biomass power plants are estimated in GREET since no EIA projections are available.

**TABLE 3.9 GREET Default Shares of Gaseous Diffusion and Centrifuge Technologies for Uranium Enrichment**

| Year | LWR: electric generation | | HTGR: electric generation | | HTGR: $H_2$ production | |
|---|---|---|---|---|---|---|
| | Gaseous diffusion | Centrifuge | Gaseous diffusion | Centrifuge | Gaseous diffusion | Centrifuge |
| 1990 | 93% | 7% | 93% | 7% | 93% | 7% |
| 1995 | 87% | 13% | 87% | 13% | 87% | 13% |
| 2000 | 57% | 43% | 57% | 43% | 57% | 43% |
| 2005 | 30% | 70% | 30% | 70% | 30% | 70% |
| 2010 | 25% | 75% | 25% | 75% | 25% | 75% |
| 2015 | 15% | 85% | 15% | 85% | 15% | 85% |
| 2020 | 10% | 90% | 10% | 90% | 10% | 90% |

**TABLE 3.10 Default Shares of Power Plant Technologies**

| Year | NGCC share of total NG power plant capacity | NG Simple-cycle gas turbine share of total NG power plant capacity | Advanced coal technology share of total coal power plant capacity | Advanced biomass technology share of total biomass power plant capacity |
|---|---|---|---|---|
| 1990 | 5.0% | 30.0% | 0.0% | 0.0% |
| 1995 | 10.0% | 34.0% | 0.0% | 0.0% |
| 2000 | 20.0% | 36.0% | 0.0% | 0.0% |
| 2005 | 41.0% | 36.0% | 0.0% | 0.0% |
| 2010 | 44.0% | 36.0% | 0.0% | 0.0% |
| 2015 | 46.0% | 37.0% | 1.0% | 1.0% |
| 2020 | 48.0% | 38.0% | 3.0% | 3.0% |

As mentioned earlier in discussions of several fuel pathways, the energy and emission credits from the co-generated electricity are automatically estimated in GREET if you select electricity export from several fuel production plants with the design option of electricity export. The GREET model provides various types of electricity/electricity mix which could be displaced by the co-generated electricity from fuel production plants (see Figure 3.18).

**For electricity co-generated in NG-based fuel production plants, the electricity type for displacement can be:**

- average electricity generation mix (consistent with your selection of electricity generation mix for stationary use [average generation mix])
- natural gas combined cycle (NGCC) electricity
- coal integrated gasification combined cycle (IGCC) electricity
- biomass IGCC electricity

**For electricity co-generated in coal-based fuel production plants, the electricity type for displacement can be:**

- average electricity generation mix (consistent with your selection of electricity generation mix for stationary use [average generation mix])
- NGCC electricity
- coal IGCC electricity

**For electricity co-generated in biomass-based fuel production plants, the electricity type for displacement can be:**

- average electricity generation mix (consistent with your selection of electricity generation mix for stationary use [average generation mix])
- NGCC electricity
- biomass IGCC electricity

The vehicle technology available for electricity use in the electricity tab is the electric vehicle as shown in Figure 3.18 (electricity is also used in GC HEVs and in FCVs fueled by $H_2$ from electrolysis at refueling stations).

## 3.9 Key Simulation Options for Biodiesel Production Pathways

Methyl or ethyl esters, produced from vegetable oils or animal fats, are commonly called biodiesel. In the United States, biodiesel is mainly produced from soybeans, while in Europe, biodiesel is produced primarily from rapeseeds. The GREET model includes the soybean-to-biodiesel production pathway.

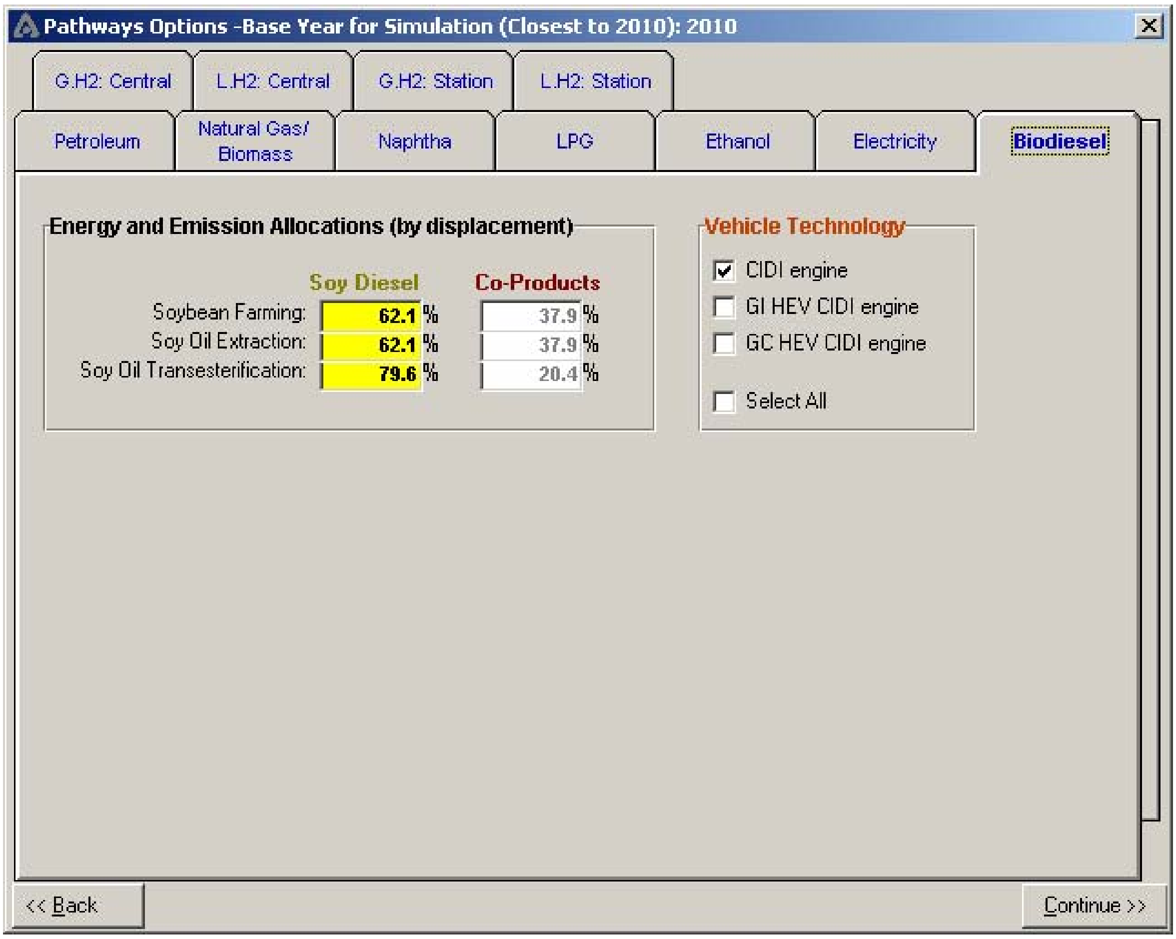


**FIGURE 3.19 Biodiesel production pathway options**

In addition to the production of the biodiesel fuel, the soybean-to-biodiesel pathway generates co-products such as soy meal and glycerin. GREET allocates emissions and energy use burdens for each process between the biodiesel and its co-products. The default energy use and emission splits in the soybean farming, soy oil extraction, and soy oil transesterification processes are 62.1%, 62.1%, and 79.6%, respectively, based on a displacement method, as shown in Figure 3.19. The input data for GREET biodiesel simulations are primarily from a 1998 study by the National Renewable Energy Laboratory (NREL) and the U.S. Department of Agriculture (USDA).

The **vehicle technology options for biodiesel are**

- CIDI engine
- GI HEV with CIDI engine
- GC HEV with CIDI engine

Biodiesel is blended with petroleum diesel for vehicle applications.

## 3.10 Key Simulation Options for Gaseous $H_2$ Production in Central Plants

**For central plant scenarios, $GH_2$ can be produced from:**

- NG via SMR
- solar energy via photovoltaic
- nuclear energy via TCWC using steam from HTGR
- nuclear energy via electrolysis using electricity and high-temperature steam from HTGR
- coal via gasification
- biomass via gasification

As explained in section 3.1, the GREET model provides the market shares for each $GH_2$ feedstock source.

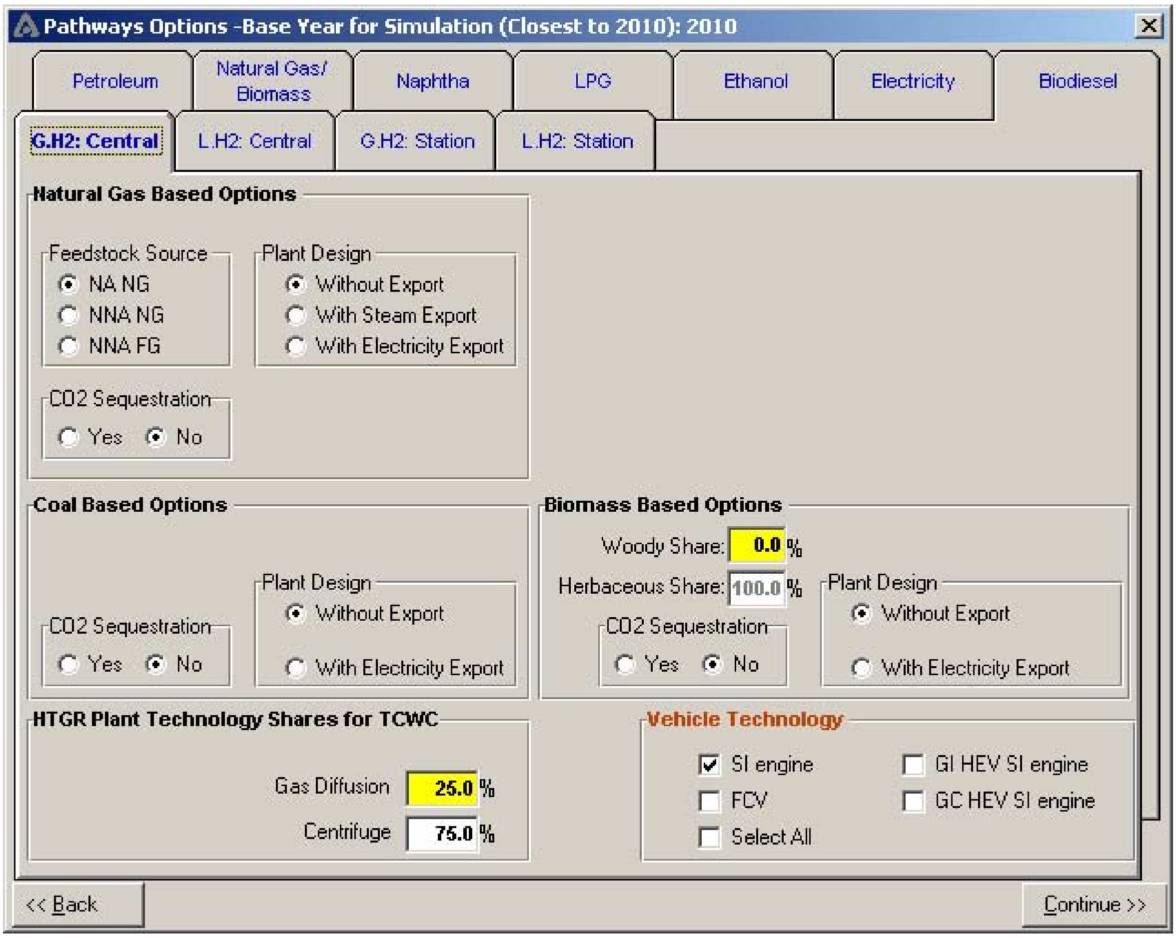


**FIGURE 3.20 $GH_2$ production in central plants**

As shown in Figure 3.20, **for the NG-based $GH_2$ production pathway, GREET can simulate $H_2$ production from:**

- North American NG
- non-North American NG
- non-North American FG feedstock sources

For the non-North America sources, the feedstock is converted into liquefied natural gas (LNG) for transportation to North America, where $GH_2$ is produced.

The **plant design options for producing NG-based $GH_2$ fuel include:**

- without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The default feedstock source for $GH_2$ production in GREET is North American NG and the default plant design type is without steam or electricity export.

As shown in Figure 3.20, the **plant design options for producing $GH_2$ from coal- and biomass-based $H_2$ are:**

- without electricity export
- with electricity export

For the latter option, the energy and emission credits from the co-generated electricity are automatically estimated in GREET. The default plant design type is without electricity export.

Note that the amount of $CO_2$ emissions from NG, coal, and biomass-based $H_2$ plants is quite large (in fact, all carbon contained in each of the feedstock sources ends up as $CO_2$). GREET includes the option for sequestrating $CO_2$ emissions in NG, coal, and biomass-based $H_2$ plants. Because $CO_2$ emissions from some processes in NG, coal, and biomass-based $H_2$ plants cannot be sequestrated, it is not realistic to specify 100% $CO_2$ sequestration for these pathways in GREET. If $CO_2$ sequestration is selected, a default $CO_2$ sequestration rate of 85% is applied (which is not allowed to change through GREETGUI), and an energy penalty and related emissions are accounted for by the GREET model. The GREET default option is without $CO_2$ sequestration for the NG, coal, and biomass-based $H_2$ plants (see Figure 3.20).

$GH_2$ can be produced from woody biomass and herbaceous biomass via gasification. The GREET model provides the market shares of each $GH_2$ biomass-based feedstock source (see Figure 3.20). The default biomass-based feedstock market share is 100% herbaceous biomass.

For the nuclear-based $H_2$ production via thermo-chemical water cracking (TCWC), you can specify the technology shares of uranium enrichment in this pathway. The technologies used for uranium enrichment include gaseous diffusion and centrifuge enrichment, and the market shares of these two technologies may change over time. The GREET default shares of gaseous diffusion and centrifuge technologies for uranium enrichment are shown in Table 3.9. These default enrichment technology shares used for the production of $H_2$ are assumed to be the same as those used for HTGR nuclear electricity generation.

The **vehicle technology options for $GH_2$ are:**

- SI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV

## 3.11 Key Simulation Options for Liquid $H_2$ Production in Central Plants

**In central plants, $LH_2$ can be produced from:**

- NG via SMR
- solar energy via photovoltaic
- nuclear energy via TCWC using steam from HTGR
- nuclear energy via electrolysis using electricity and high-temperature steam from HTGR
- coal via gasification
- biomass via gasification

As explained in section 3.1, the GREET model provides the market share of each $LH_2$ feedstock source.

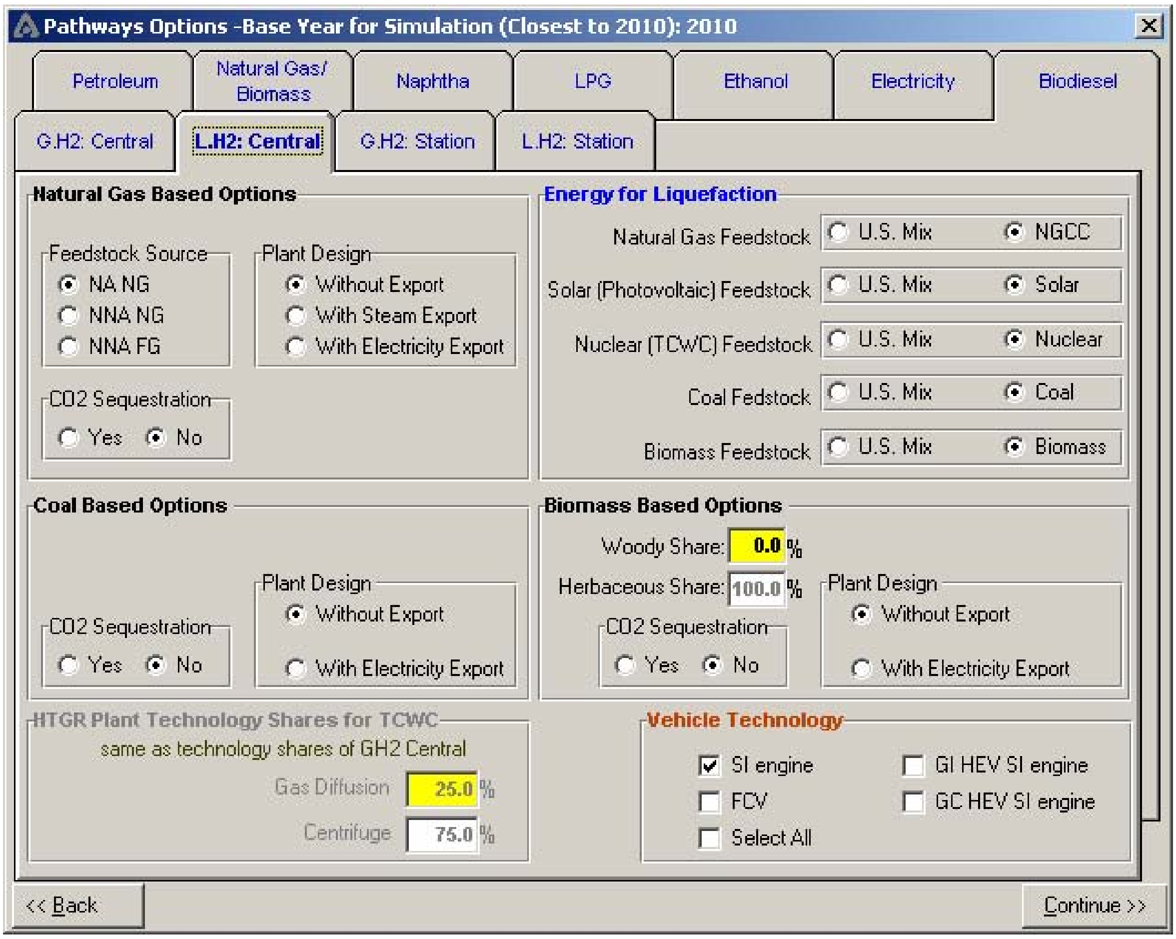


**FIGURE 3.21 $LH_2$ production in central plants**

As shown in Figure 3.21, **for NG-based $LH_2$ production pathway, GREET can simulate $H_2$ production from:**

- North American NG
- non-North American NG
- non-North American FG

For non-North America NG source, GREET assumes that $LH_2$ is produced outside of North America, and is then transported to North America.

The **plant design options for producing NG-based $LH_2$ fuel are:**

- without steam or electricity export
- with steam export
- with electricity export

For the second and third options, the energy and emission credits from the co-generated steam or electricity are automatically estimated in GREET. The default feedstock source for $LH_2$ production in GREET is North American NG and the default plant design type is without steam or electricity export.

As shown in Figure 3.21, the **plant design options for producing $LH_2$ fuel for coal- and biomass-based $H_2$ plants are:**

- without electricity export
- with electricity export

For the latter option, the energy and emission credits from the co-generated electricity are automatically estimated in GREET. The default plant design type is without electricity export.

$LH_2$ can be produced from woody biomass and herbaceous biomass via gasification. The GREET model provides the market shares of each $LH_2$ biomass-based feedstock source (see Figure 3.21). The default biomass-based feedstock market share is 100% herbaceous biomass.

Note that the liquefaction of $H_2$ requires a large amount of electricity. You may select between NGCC electricity and the average electricity generation mix for the liquefaction of $H_2$ in NG-based central plants. The default electricity option for $H_2$ liquefaction in the NG-based $H_2$ plants is NGCC electricity.

**For the solar-based $H_2$ pathway**, you may select between solar electricity and the average electricity generation mix for the liquefaction of $H_2$ in solar-based central plants. The default electricity option for $H_2$ liquefaction in the solar-based $H_2$ plants is solar electricity.

**For nuclear-based $H_2$ production via TCWC**, you may select between HTGR nuclear electricity and the average electricity generation mix for the liquefaction of $H_2$. The default electricity option for $H_2$ liquefaction in the nuclear-based $H_2$ plants via TCWC is HTGR nuclear electricity. The technology shares of uranium enrichment for the pathway of nuclear-based $LH_2$ production via TCWC are consistent with those shown for $GH_2$ production in central plants (Figure 3.20).

**For the coal-based $H_2$ production pathway**, you can select between advanced coal electricity and the average electricity mix for the liquefaction of $H_2$. The default electricity option for $H_2$ liquefaction in the coal-based $H_2$ plants is advanced coal electricity.

**For the biomass-based $H_2$ production pathway**, you can select between advanced biomass electricity and the average electricity mix for the liquefaction of $H_2$. The default electricity option for $H_2$ liquefaction in the biomass-based $H_2$ plants is advanced biomass electricity.

For any of the $LH_2$ production pathways mentioned above, the average electricity generation mix used for $H_2$ liquefaction is consistent with that specified in the electricity tab for stationary use (see Figure 3.18).

GREET assumes that (a) hydrogen liquefaction plants are co-located with the hydrogen production plants, (b) that $LH_2$ is transported by barge and rail, and (c) $LH_2$ is distributed by truck. It is speculative to determine whether $LH_2$ would be produced this way or in a separate location. However, since $H_2$ liquefaction could occur in a separate location, future versions of GREET may be expanded to accommodate such possibility.

Note that even with the assumption that $H_2$ production and liquefaction are occurring at the same location, the only pathway for $LH_2$ where $H_2$ production and liquefaction are coupled together (in terms of using the same feedstock for both production and liquefaction) is $LH_2$ production in central plants via high-temperature electrolysis using HTGR-generated electricity and steam. For all other $LH_2$ production pathways, $H_2$ production and liquefaction are decoupled in the sense that $H_2$ production and liquefaction could be fueled with different energy feedstock sources.

$CO_2$ sequestration simulation options in NG, coal, and biomass-based $LH_2$ plants are the same as those for GH2 plants, discussed in section 3.10.

The **vehicle technology options for $LH_2$ are:**
- SI engine
- GI HEV with SI engine
- GC HEV with SI engine
- FCV

## 3.12 Key Simulation Options for Gaseous $H_2$ Production at Refueling Stations

**At refueling stations, $GH_2$ can be produced from:**
- NG via SMR
- conventionally generated electricity via electrolysis of water
- EtOH
- MeOH

As explained in section 3.1, GREET provides the market shares of each $GH_2$ feedstock source. Currently, the methanol-to-$GH_2$ pathway is just a placeholder in GREET, i.e., the model structure is completely in place for this specific pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers. Efforts are underway to search for data in publicly available sources.

As shown in Figure 3.22, **for the NG-based $H_2$ production pathway, GREET can simulate $H_2$ production from:**

- North American NG
- non-North American NG
- non-North American FG

For non-North America sources, GREET assumes that non-North American NG and FG are converted into LNG for transportation to North America, where $GH_2$ is produced. The default feedstock source for NG-based $H_2$ production in GREET is North American NG.

As shown in Figure 3.22, GREET allows you to select **one of seven types of electricity for $GH_2$ production via electrolysis at refueling stations. These include the electricity generated from:**

- oil power plants
- NG power plants
- coal power plants
- nuclear power plants (LWR or HTGR)
- hydro power plants
- NGCC turbine power plants
- marginal generation mix

The marginal generation mix is consistent with the marginal electricity generation mix for transportation use selected earlier in the electricity tab (see Figure 3.18). The default electricity option for $GH_2$ electrolysis at refueling stations is the marginal electricity generation mix.

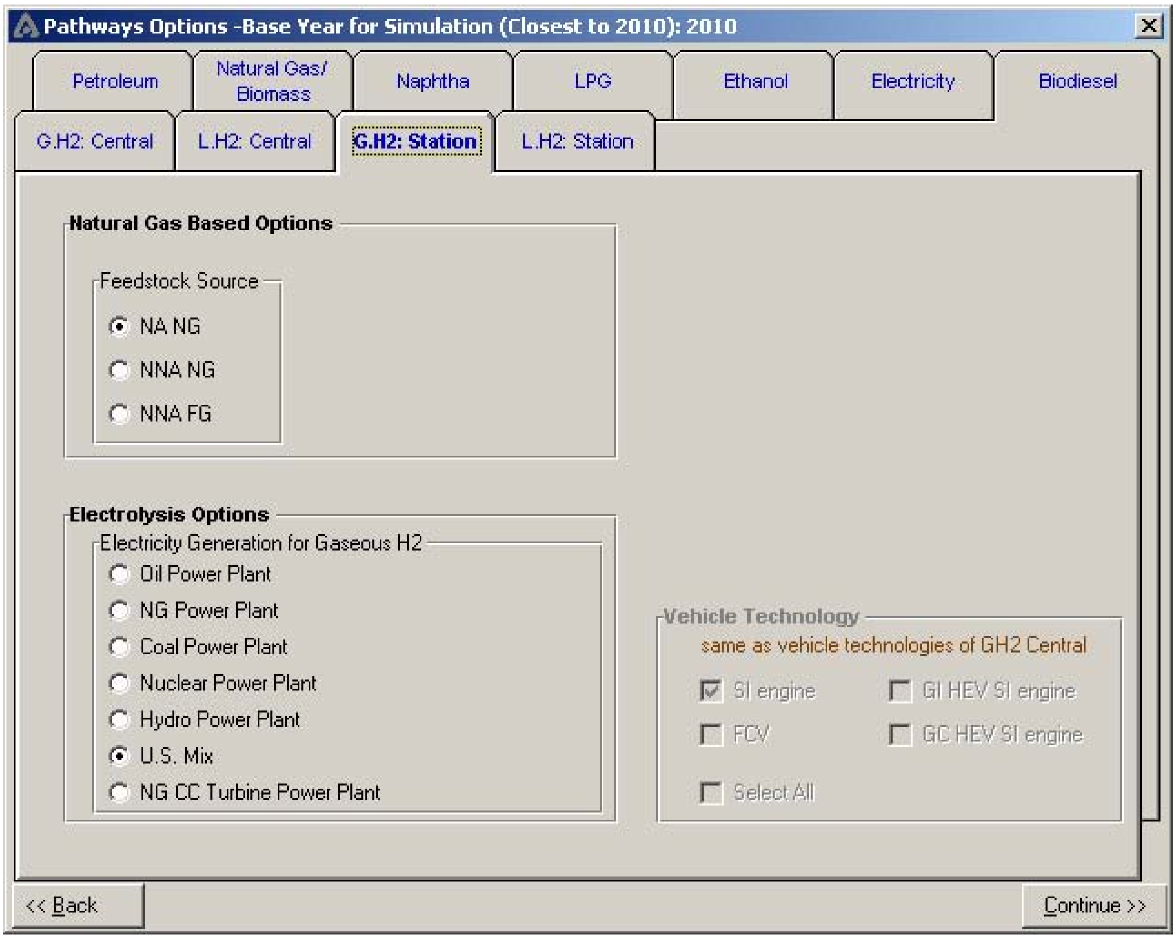


**FIGURE 3.22 $GH_2$ production at refueling stations**

## 3.13 Key Simulation Options for Liquid $H_2$ Production at Refueling Stations

**At refueling stations, $LH_2$ can be produced from:**

- NG via SMR
- conventionally generated electricity via electrolysis of water
- EtOH
- MeOH

GREET provides the market shares of each LH2 feedstock source as explained in section 3.1 above. Currently, the methanol-to-$LH_2$ pathway is a placeholder in GREET, i.e., the model structure is completely in place for this specific pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers. Efforts are continued to search for data in publicly available sources.

As shown in Figure 3.23, for NG-based $H_2$ production pathway, **GREET can simulate $LH_2$ production from:**

- North American NG
- non-North American NG
- non-North American FG

For non-North America sources, GREET assumes that non-North American NG and FG are converted into LNG for transportation to North America, and $LH_2$ is produced at North American refueling stations. The default feedstock source for NG-based $H_2$ production in GREET is North American NG.

As shown in Figure 3.23, you can select one of seven types of electricity for $LH_2$ production via electrolysis at refueling stations. **These include the electricity generated from:**

- oil power plants
- NG power plants
- coal power plants
- nuclear power plants (LWR or HTGR)
- hydro power plants
- NGCC turbine power plants
- marginal generation mix

The marginal generation mix is consistent with the selection of the marginal electricity generation mix for transportation use selected earlier in the electricity tab (see Figure 3.18). The default electricity option for $LH_2$ electrolysis at refueling stations is the marginal electricity generation mix.

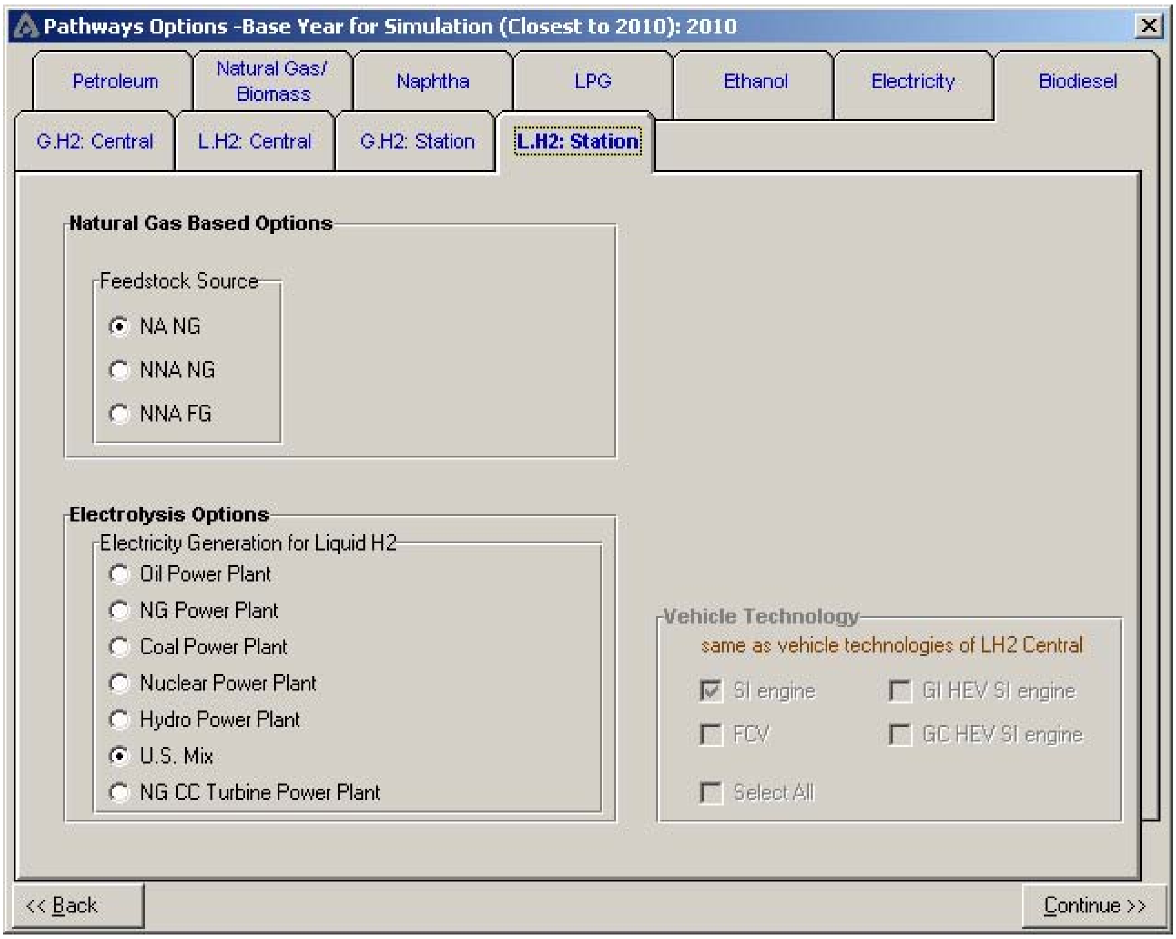


**FIGURE 3.23 $LH_2$ production at refueling stations**

## 3.14 Key Simulation Options for Alternative Fuel Blends

In GREETGUI, you can specify the volumetric shares of alternative fuels for blending with gasoline or diesel (see Figure 3.24). The default blending levels of alternative fuels with gasoline or diesel are shown in Table 3.11.

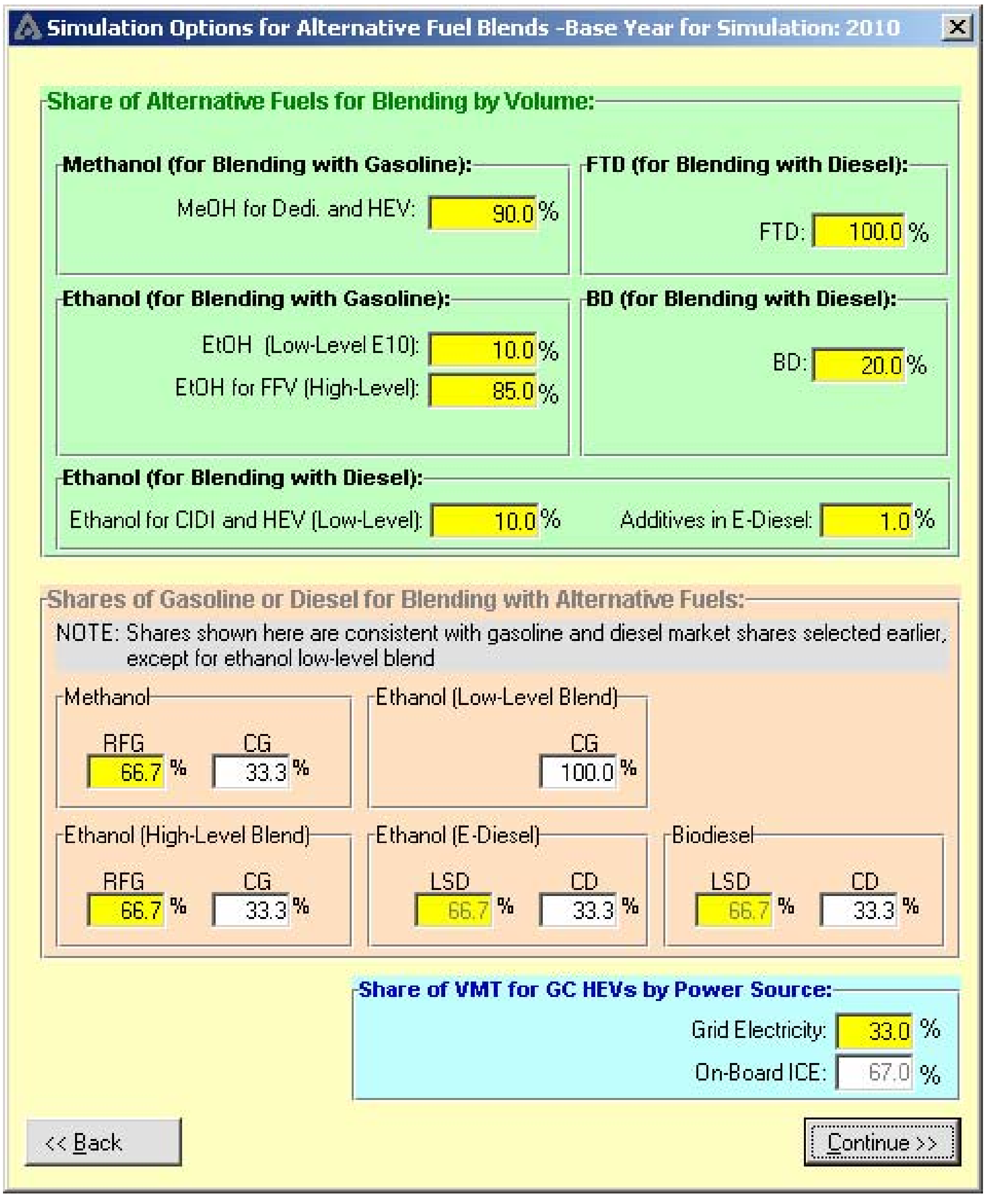


**FIGURE 3.24 Simulation options for alternative fuel blends**

Ethanol-gasoline blends have two blending levels in GREET: low-level blend with ethanol, which has ethanol volumetric content of 5–15% (the default value set in GREET is 10%), and high-level blend with ethanol, which has ethanol volumetric content of 15–90% (the default value set in GREET is 85% for FFV and 90% for other vehicle technologies such as dedicated vehicle and HEV, respectively).

**If you specify a different blend level (e.g., 40% for the high-level ethanol-gasoline blend) far from the default, you should revise the vehicle fuel economy and emission factors in GREET to reflect the new blend level.**

**You can select CG, RFG, or a combination of these two fuels, with specific market share of each, for blending with methanol and ethanol.** GREET assumes that ethanol is blended with CG for low-level blends (similar to wintertime oxygenated fuel) and with market share-weighted combination of CG and RFG for high-level blends. Note that ethanol use as RFG oxygenate is simulated separately under the RFG simulation options (see Figure 3.4), not in the ethanol blend simulation options. Similar to ethanol high-level blends, GREET assumes that methanol is blended with market share-weighted combination of CG and RFG.

**You can select CD, LSD, or a combination of these two fuels, with specific market share of each, for blending with ethanol, FTD and biodiesel.** GREET assumes that ethanol, FTD, and biodiesel are blended with the market share-weighted combination of CD and LSD.

**For GC HEV technologies, you must specify the share of VMT by power source.** GREET assumes that 33% of total VMT is powered by grid electricity, and the rest is powered by an on-board internal combustion engine (ICE).

**TABLE 3.11 Default Shares of Alternative Fuels for Blending With Gasoline or Diesel**

| Alternative fuels | Blending share (vol, %) |
|---|---|
| For blending with gasoline | |
| Methanol for dedicated engine and HEV | 90% |
| Methanol for FFV | 85% |
| Ethanol (low-level, E10) | 10% |
| Ethanol (high-level) for FFV | 85% |
| Ethanol (high-level) for dedicated engine and HEV | 90% |
| For blending with diesel | |
| FTD | 100% |
| Biodiesel | 20% |
| Ethanol for CIDI engine and HEV | 10% |
| Additives in ED | 1% |

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# 4. Key Parametric Assumptions

## 4.1 Key Parametric Assumptions for Production of Petroleum-Based Fuels

Energy efficiencies of crude oil recovery and the refining processes associated with the production of petroleum-based fuels are considered key parameters that you can specify in GREETGUI as shown in Figure 4.1. Since these parameters may change over time, time-series tables were developed in GREET for the energy efficiencies of petroleum-related processes. Table 4.1 shows the GREET default values for 2010.

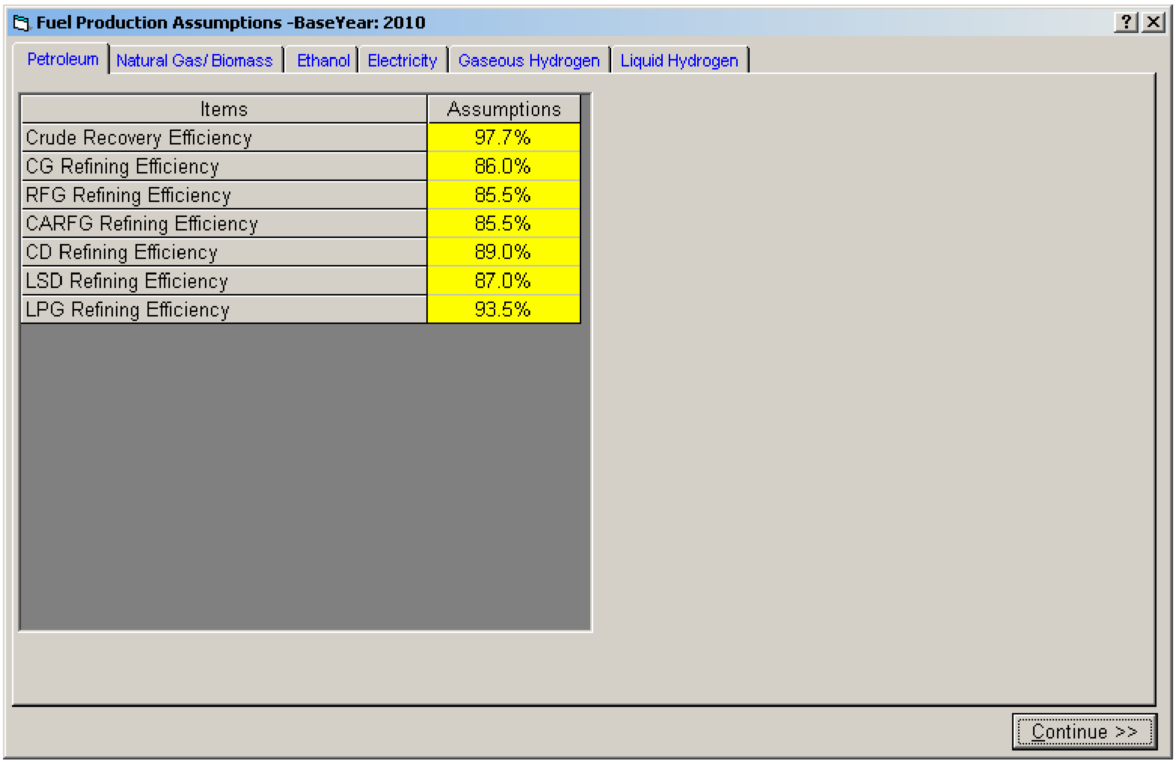


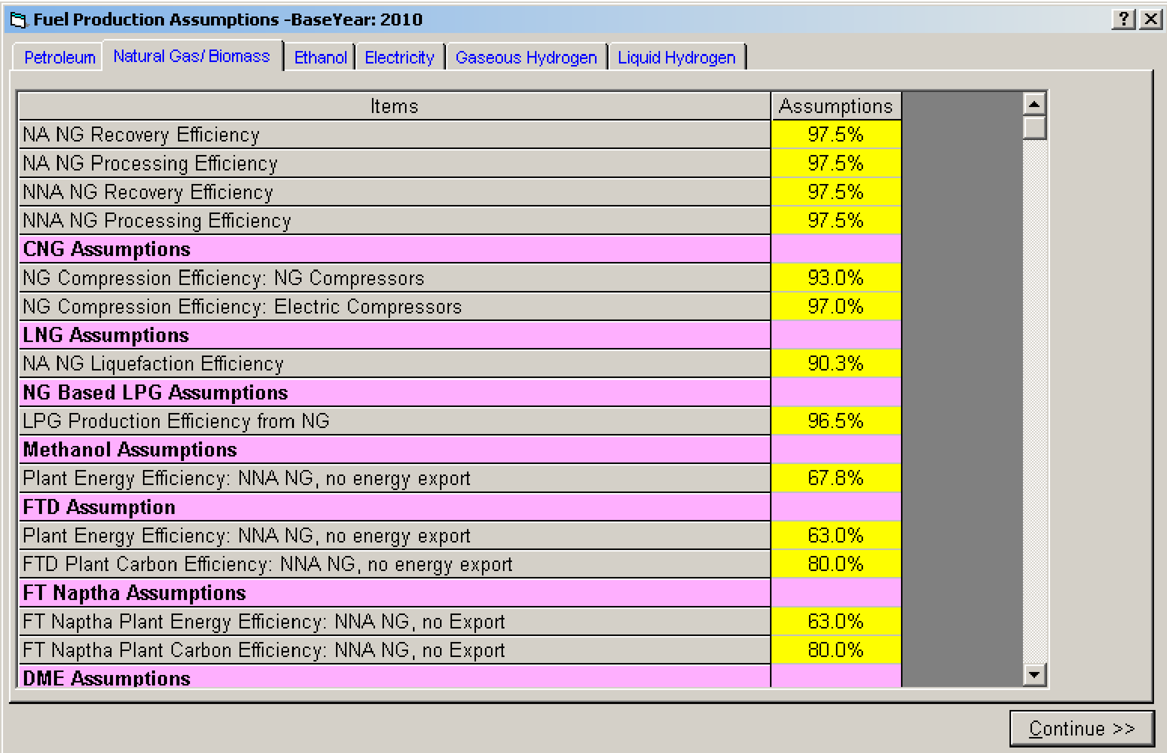

**FIGURE 4.1 Key parametric assumptions for production of petroleum-based fuels**

**TABLE 4.1 Default Energy Efficiencies for Petroleum-Related Processes**

| | Energy efficiency, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Crude Recovery** | **CG Refining** | **RFG Refining** | **CARFG Refining** | **CD Refining** | **LSD Refining** | **LPG Refining** | **Naphtha Refining** |
| 2010 | 98.0 | 86.0 | 85.5 | 85.5 | 89.0 | 87.0 | 93.5 | 91.0 |

## 4.2 Key Parametric Assumptions for the Production of NG-Based Fuels

Energy efficiencies associated with natural gas (NG) recovery and processing, NG-based fuels production, and steam/electricity credits are key parameters that you can specify in GREETGUI as shown in Figure 4.2. Since many of these parameters may change over time, time-series tables were developed in GREET for energy efficiencies and steam/electricity credits of NG-related processes. These tables are discussed below.


Fuel Production Assumptions -BaseYear: 2010

Petroleum | Natural Gas/ Biomass | Ethanol | Electricity | Gaseous Hydrogen | Liquid Hydrogen

| Items | Assumptions |
|---|---|
| NA NG Recovery Efficiency | 97.5% |
| NA NG Processing Efficiency | 97.5% |
| NNA NG Recovery Efficiency | 97.5% |
| NNA NG Processing Efficiency | 97.5% |
| **CNG Assumptions** | |
| NG Compression Efficiency: NG Compressors | 93.0% |
| NG Compression Efficiency: Electric Compressors | 97.0% |
| **LNG Assumptions** | |
| NA NG Liquefaction Efficiency | 90.3% |
| **NG Based LPG Assumptions** | |
| LPG Production Efficiency from NG | 96.5% |
| **Methanol Assumptions** | |
| Plant Energy Efficiency: NNA NG, no energy export | 67.8% |
| **FTD Assumption** | |
| Plant Energy Efficiency: NNA NG, no energy export | 63.0% |
| FTD Plant Carbon Efficiency: NNA NG, no energy export | 80.0% |
| **FT Naptha Assumptions** | |
| FT Naptha Plant Energy Efficiency: NNA NG, no Export | 63.0% |
| FT Naptha Plant Carbon Efficiency: NNA NG, no Export | 80.0% |
| **DME Assumptions** | |

Continue >>

**FIGURE 4.2 Key parametric assumptions for production of NG-based fuels**

### 4.2.1 Steam Production

Energy efficiency of steam boilers is a key parameter for steam co-generation in many fuel production facilities. This parameter is used to calculate the steam export credit for fuel production plants with steam export. The default value of steam boiler energy efficiency in GREET is 80%.

### 4.2.2 NG Recovery and Processing

The default energy efficiencies for NG recovery and processing in 2010 in GREET are shown in Table 4.2.

**TABLE 4.2 Default Energy Efficiencies for NG Recovery and Processing**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Recovery | Processing | Recovery | Processing | Recovery | Processing |
| 2010 | 97.2% | 97.2% | 97.2% | 97.2% | 97.2% | 97.2% |

[a] North American
[b] non-North American

### 4.2.3 NG Compression and Liquefaction

The default energy efficiencies for NG compression and liquefaction in 2010 are shown in Table 4.3. When non-North American (NNA) NG or NNA FG is selected as the feed stock source for any of the CNG, $GH_2$, or station $LH_2$ production, LNG is assumed to be an intermediate fuel to bring NNA NG or FG to North America, which is accounted for in the simulation of these specific pathways.

**TABLE 4.3 Default Energy Efficiencies for NG Compression and Liquefaction**

| Year | Compression | | Liquefaction | | |
|---|---|---|---|---|---|
| | NG compressor | Electric compressor | NA NG | NNA NG | NNA FG |
| 2010 | 93.0% | 97.0% | 91.0% | 91.0% | 91.0% |

### 4.2.4 NG-Based LPG Production

The default energy efficiency for liquefied petroleum gas (LPG) production from NG in 2010 is 96.5%.

### 4.2.5 Methanol Production

The default energy efficiencies and steam/electricity credits for methanol production in 2010 are shown in Tables 4.4 and 4.5, respectively.

**TABLE 4.4 Default Energy Efficiencies for Methanol Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 67.5% | 64.0% | 67.5% | 64.0% | 67.5% | 64.0% |

[a] North American
[b] non-North American

**TABLE 4.5 Default Steam Credit (Btu/mmBtu of Fuel Produced) or Electricity Credit (kWh/mmBtu of fuel produced) for Methanol Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 78,130 | 6.87 | 78,130 | 6.87 | 78,130 | 6.87 |

[a] North American
[b] non-North American

### 4.2.6 FTD Production

The default energy efficiencies, steam/electricity credits, and carbon efficiencies for FTD production in 2010 are shown in Tables 4.6, 4.7, and 4.8, respectively.

**TABLE 4.6 Default Energy Efficiencies for FTD Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 63.0% | 55.0% | 63.0% | 55.0% | 63.0% | 55.0% |

[a] North American
[b] non-North American

**TABLE 4.7 Default Steam Credit (Btu/mmBtu of Fuel Produced) or Electricity Credit (kWh/mmBtu of fuel produced) for FTD Production**

| Year | Feedstock: NA NG | | Feedstock: NNA NG | | Feedstock: NNA FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 202,000 | 17.76 | 202,000 | 17.76 | 202,000 | 17.76 |

**TABLE 4.8 Default Carbon Efficiencies for FTD Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% |

[a] North American
[b] non-North American

### 4.2.7 DME Production

The default energy efficiencies and steam/electricity credits for DME production in 2010 are shown in Tables 4.9 and 4.10, respectively.

**TABLE 4.9 Default Energy Efficiencies for DME Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 70.0% | 68.0% | 70.0% | 68.0% | 70.0% | 68.0% |

[a] North American
[b] non-North American

**TABLE 4.10 Default Steam Credit (Btu/mmBtu of fuel produced) or Electricity Credit (kWh/mmBtu of fuel produced) for DME Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 44,000 | 3.87 | 44,000 | 3.87 | 44,000 | 3.87 |

[a] North American
[b] non-North American

### 4.2.8 Naphtha Production

The default energy efficiencies, steam/electricity credits and carbon efficiencies for FT naphtha production in 2010 are shown in Tables 4.11, 4.12, and 4.13, respectively.

**TABLE 4.11 Default Energy Efficiencies for FT Naphtha Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 63.0% | 55.0% | 63.0% | 55.0% | 63.0% | 55.0% |

[a] North American
[b] non-North American

**TABLE 4.12 Default Steam Credit (Btu/mmBtu of fuel produced) or Electricity Credit (kWh/mmBtu of fuel produced) for FT Naphtha Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 202,000 | 17.76 | 202,000 | 17.76 | 202,000 | 17.76 |

[a] North American
[b] non-North American

**TABLE 4.13 Default Carbon Efficiencies for FT Naphtha Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% |

[a] North American
[b] non-North American

## 4.3 Key Parametric Assumptions for Production of Biomass-Based Fuels

Energy efficiencies and electricity credit associated with the production of biomass-based fuels are key parameters that you can specify in GREETGUI as shown in Figure 4.3. Since many of these parameters may change over time, time-series tables were developed in GREET for energy efficiencies and electricity credits of biomass-related processes.

Energy use in biomass farming and $CO_2$ emissions due to land use changes by biomass farming are also key parameters that you can specify in GREETGUI in the *Ethanol* tab as shown in Figure 4.4 (detailed information is provided in section 4.4).

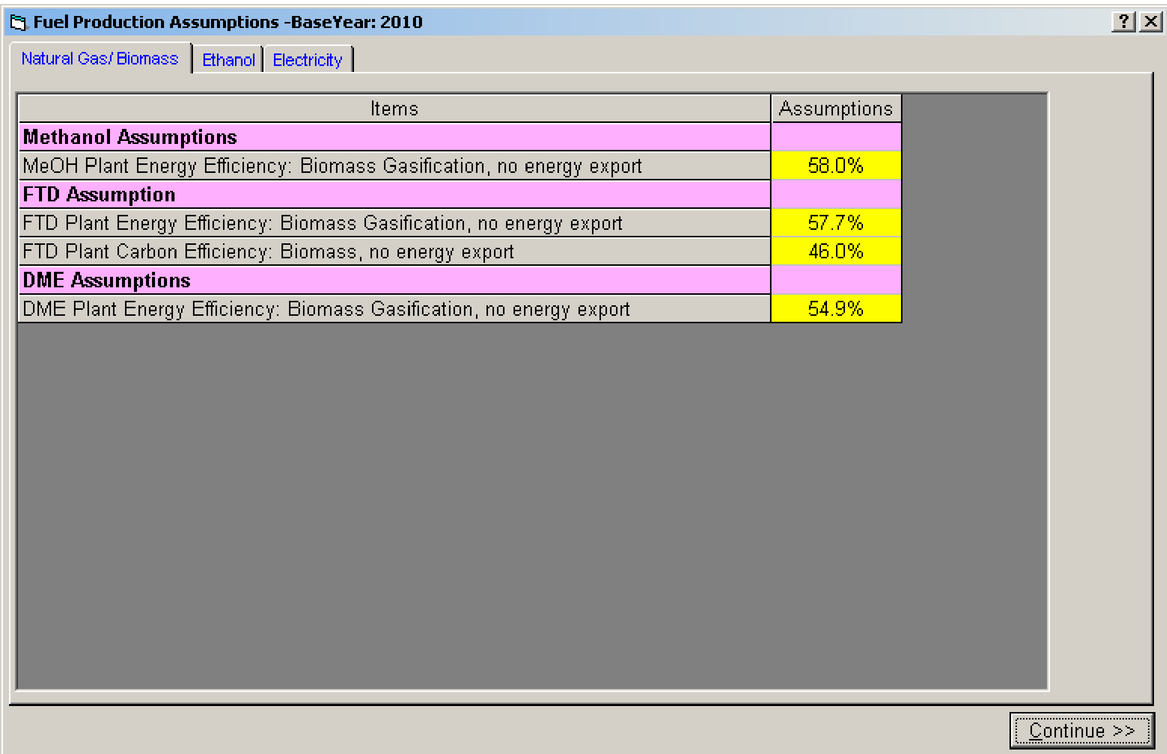



**FIGURE 4.3 Key parametric assumptions for production of biomass-based fuels**

### 4.3.1 Methanol Production

The default energy efficiencies and electricity credits for biomass-based methanol production in 2010 are shown in Tables 4.14 and 4.15, respectively.

Note that currently, this pathway is just a placeholder in GREET, i.e., the model structure is completely in place for this specific fuel pathway, but the parameter values are uncertain. Therefore, you should exercise caution when using the GREET default numbers. Efforts are underway to search for reliable data in publicly available sources.

### 4.3.2 FTD Production

The default energy efficiencies, electricity credits and carbon efficiencies for biomass-based FTD production in 2010 are shown in Tables 4.14, 4.15, and 4.16, respectively.

Note that available data on this pathway are very limited. The default data in GREET are based on a study conducted for *The Role of Biomass in America's Energy Future* (for details, see Wu et al. 2005). In that study, only one production scenario, biomass-based Fischer-Tropsch diesel (FTD) with electricity co-generation via gas turbine combined cycle (GTCC), was simulated. Electricity was no longer a by-product, but a major energy co-product. Two methods, the allocation method and the displacement method, were applied for electricity credit partition.

In this version of GREET, data that were generated through the Role of Biomass in America's Energy Future (RBAEF) project were processed for applications to the plant designs without electricity export, while the displacement method was applied for the second design option (with electricity export). Therefore, you should exercise caution when simulating this fuel pathway. When the displacement method is applied in the simulation, the fuel production energy efficiency reduces significantly (34.4% vs. 57.7% in Table 4.14). That is because the calculated energy efficiency in this case is not accounting for the large amount of electricity co-product, while accounting for the feedstock energy used to generate the electricity co-product. The energy and emission credits from the co-generated electricity for export are automatically estimated in GREET (Table 4.15).

### 4.3.3 DME Production

The default energy efficiencies and electricity credits for biomass-based DME production in 2010 in GREET are shown in Tables 4.14 and 4.15, respectively.

Note that available data on this pathway are very limited. The default data in GREET are based on a study conducted for *The Role of Biomass in America's Energy Future* (for details, see Wu et al. 2005). In that study, only one production scenario, biomass-based DME with electricity co-generation via GTCC, was simulated. Electricity was no longer a by-product, but a major energy co-product. Two methods, allocation method and displacement method, were applied for electricity credit partition.

In this version of GREET, data that were generated through the RBAEF project were processed for applications to the plant designs without electricity export, while the displacement method was applied for the second design option (with electricity export). Therefore, you should exercise caution when simulating this fuel pathway. When the displacement method is applied in the simulation, the fuel production energy efficiency reduces significantly (24.5% vs. 54.9% in Table 4.14). That is because the calculated energy efficiency in this case is not accounting for the large amount of electricity co-product, while accounting for the feedstock energy used to generate the electricity co-product. The energy and emission credits from the co-generated electricity for export are automatically estimated in GREET (Table 4.15).

**TABLE 4.14 Default Energy Efficiencies for Biomass-Based Fuel Production**

| | Methanol[a] | | FTD | | DME | |
|---|---|---|---|---|---|---|
| Year | no export | with kWh export | no export | with kWh export | no export | with kWh export |
| 2010 | 58.0% | 43.0% | 57.7% | 34.4%[b] | 54.9% | 24.5%[b] |

[a] Placeholder default values.

[b] The efficiency here does not take into account the large amount of electricity co-produced with this option. The co-produced electricity is taken into account in GREET separately.

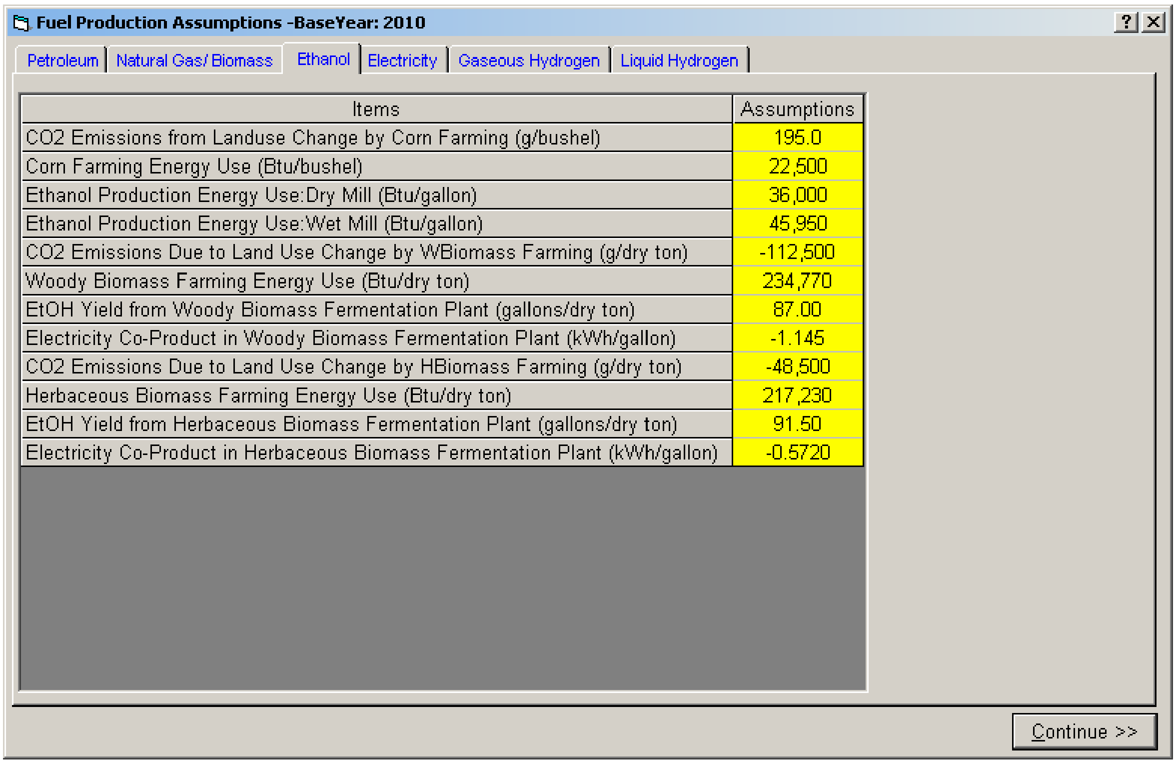
**TABLE 4.15 Default Electricity Credit (kWh/mmBtu of fuel produced) for Biomass-Based Fuel Production**

| Year | Methanol[a] | FTD | DME |
|---|---|---|---|
| 2010 | 76.50 | 198.40 | 363.20 |

[a] Placeholder default values.

## 4.4 Key Parametric Assumptions for Ethanol Production

Energy use in corn/biomass farming and ethanol production, and $CO_2$ emissions due to land use changes by corn/biomass farming are key parameters that you can specify in GREETGUI as shown in Figure 4.4. Depending on the selection of different market shares of ethanol feedstock sources and different plant design types, the default assumptions shown in Figure 4.4 could change over time. Therefore, time-series tables are developed in GREET for the default assumptions of each ethanol-related process. The GREET default values for 2010 are shown in Tables 4.16, 4.17, and 4.18, respectively.


Fuel Production Assumptions -BaseYear: 2010

Petroleum | Natural Gas/ Biomass | Ethanol | Electricity | Gaseous Hydrogen | Liquid Hydrogen

| Items | Assumptions |
|---|---|
| CO2 Emissions from Landuse Change by Corn Farming (g/bushel) | 195.0 |
| Corn Farming Energy Use (Btu/bushel) | 22,500 |
| Ethanol Production Energy Use:Dry Mill (Btu/gallon) | 36,000 |
| Ethanol Production Energy Use:Wet Mill (Btu/gallon) | 45,950 |
| CO2 Emissions Due to Land Use Change by WBiomass Farming (g/dry ton) | -112,500 |
| Woody Biomass Farming Energy Use (Btu/dry ton) | 234,770 |
| EtOH Yield from Woody Biomass Fermentation Plant (gallons/dry ton) | 87.00 |
| Electricity Co-Product in Woody Biomass Fermentation Plant (kWh/gallon) | -1.145 |
| CO2 Emissions Due to Land Use Change by HBiomass Farming (g/dry ton) | -48,500 |
| Herbaceous Biomass Farming Energy Use (Btu/dry ton) | 217,230 |
| EtOH Yield from Herbaceous Biomass Fermentation Plant (gallons/dry ton) | 91.50 |
| Electricity Co-Product in Herbaceous Biomass Fermentation Plant (kWh/gallon) | -0.5720 |

Continue >>

**FIGURE 4.4 Key parametric assumptions for production of ethanol fuel**

**TABLE 4.16 Default Corn/Biomass Farming Energy Use**

| Year | Corn farming, Btu/bushel | Woody biomass farming, Btu/dry ton | Herbaceous biomass farming, Btu/dry ton |
|---|---|---|---|
| 2010 | 22,500 | 234,770 | 217,230 |

**TABLE 4.17 Default Energy Use, Yield or kWh Co-Production for Ethanol Production**

| Year | Energy use of corn-ethanol production, Btu/gal | | Woody biomass-ethanol production | | Herbaceous biomass-ethanol production | |
|---|---|---|---|---|---|---|
| | Dry milling | Wet milling | Yield: gal/dry ton | Electricity co-production: kWh/gal | Yield: gal/dry ton | Electricity co-production: kWh/gal |
| 2010 | 36,000 | 45,950 | 90.0 | -1.145 | 95.0 | -0.572 |

Note: negative values imply credit.

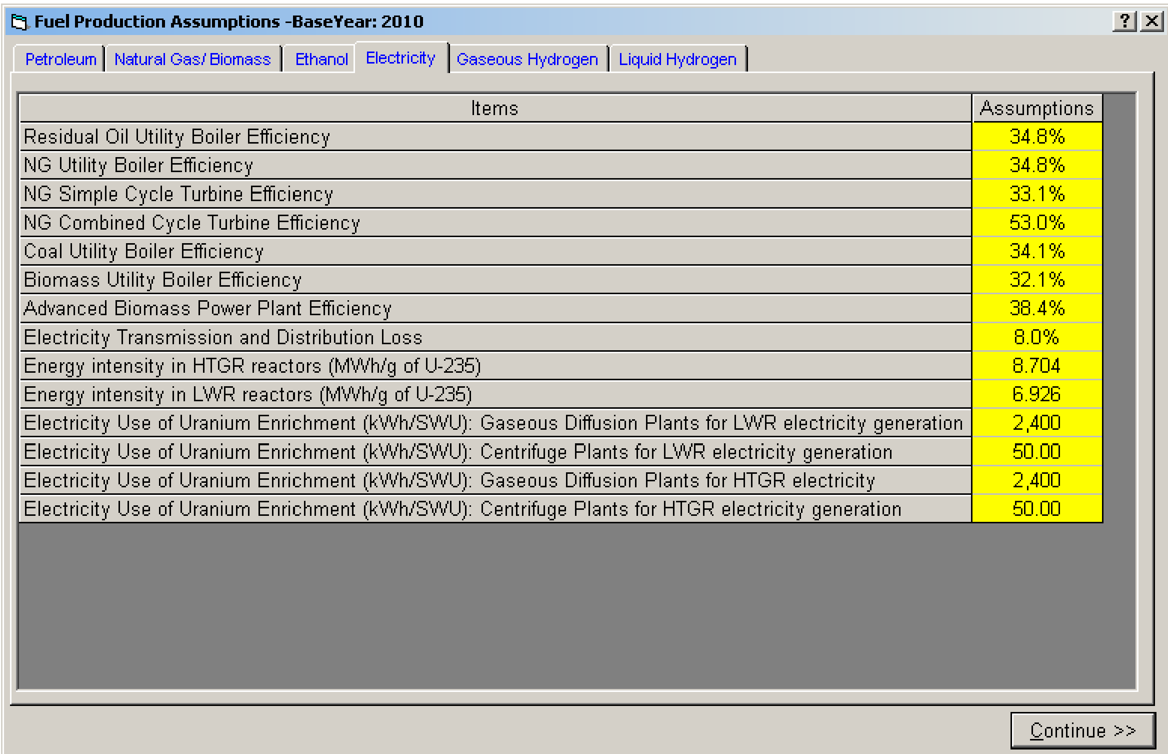
**TABLE 4.18 Default $CO_2$ Emissions Due to Land Use Change by Corn/Biomass Farming**

| Year | Corn farming, g/bushel | Woody biomass farming, g/dry ton | Herbaceous biomass farming, g/dry ton |
|---|---|---|---|
| 2010 | 195.0 | −112,500 | −48,500 |

Note: positive values imply emissions, and negative values imply sequestration.

## 4.5 Key Parametric Assumptions for Electricity Generation

Efficiency of electric power generation at various types of power plant, and the electricity transmission and distribution losses are key parameters that you can specify in GREETGUI as shown in Figure 4.5. You can also specify other key parameters for nuclear-based electricity generation processes. Since these parameters may change over time, time-series tables are developed in GREET for each electricity generation process.




| Items | Assumptions |
|---|---|
| Residual Oil Utility Boiler Efficiency | 34.8% |
| NG Utility Boiler Efficiency | 34.8% |
| NG Simple Cycle Turbine Efficiency | 33.1% |
| NG Combined Cycle Turbine Efficiency | 53.0% |
| Coal Utility Boiler Efficiency | 34.1% |
| Biomass Utility Boiler Efficiency | 32.1% |
| Advanced Biomass Power Plant Efficiency | 38.4% |
| Electricity Transmission and Distribution Loss | 8.0% |
| Energy intensity in HTGR reactors (MWh/g of U-235) | 8.704 |
| Energy intensity in LWR reactors (MWh/g of U-235) | 6.926 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for LWR electricity generation | 2,400 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for LWR electricity generation | 50.00 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for HTGR electricity | 2,400 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for HTGR electricity generation | 50.00 |

**FIGURE 4.5 Key parametric assumptions for production of electricity**

### 4.5.1 Electricity Generation Efficiencies

The default electricity generation efficiencies for different types of power plants in 2010 are shown in the Table 4.19.

### 4.5.2 Electricity Transmission and Distribution Loss

The default electricity transmission and distribution loss is 8%.

### 4.5.3 Key Parameters of Nuclear-Related Electricity Generation Processes

The GREET defaults for electricity generation intensity of nuclear power plants and the electricity use in the uranium enrichment processes in 2010 are shown in Table 4.20.

**TABLE 4.19 Default Electricity Generation Efficiencies of Various Types of Power Plants**

| | Residual oil | NG | | |
|---|---|---|---|---|
| Year | Utility boiler | Utility boiler | Simple cycle turbine | Combined cycle turbine |
| 2010 | 34.8% | 34.8% | 33.1% | 53.0% |

| | Coal | | Biomass | |
|---|---|---|---|---|
| Year | Utility boiler | Advanced combined cycle turbine | Utility boiler | Advanced combined cycle turbine |
| 2010 | 34.1% | 46.0% | 32.1% | 40.0% |

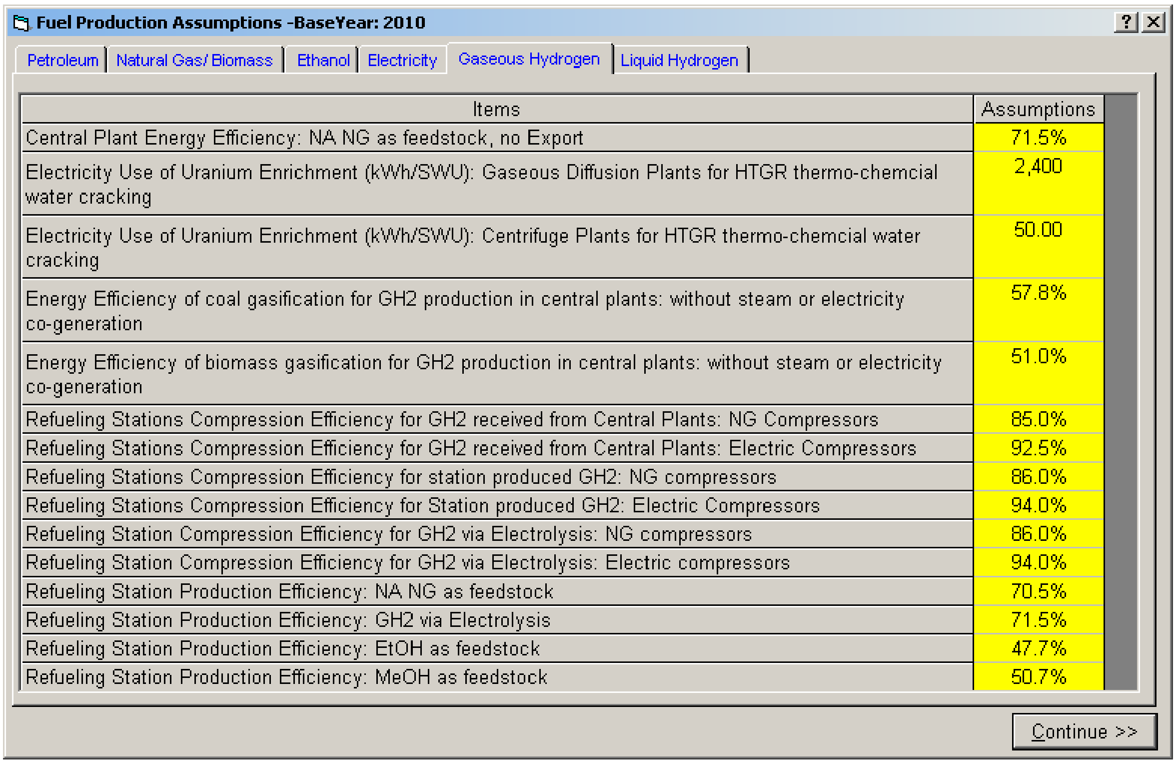
**TABLE 4.20 Default Parameters of Nuclear-Related Electricity Generation Processes**

| | Electricity generation intensity: MWh/g of $^{235}U$ | | Electricity use of uranium enrichment: kWh/SWU[a] | |
|---|---|---|---|---|
| Year | LWR | HTGR | Gaseous diffusion plant | Centrifuge plant |
| 2010 | 6.926 | 8.704 | 2,400 | 50 |

[a] SWU: separative work units.

## 4.6 Key Parameters for Gaseous $H_2$ Production Pathways

Energy efficiencies for $H_2$ production from various feedstock sources, steam/electricity credits, energy use for $CO_2$ sequestration, and $H_2$ compression efficiencies are key parameters that you can specify for $GH_2$ production pathways in the GREETGUI as shown in Figure 4.6. Depending on the selection of different $GH_2$ feedstock sources or production sites, these assumptions may change over time. Therefore, time-series tables were built in GREET for each $H_2$ production process.



Fuel Production Assumptions -BaseYear: 2010

Petroleum | Natural Gas/ Biomass | Ethanol | Electricity | Gaseous Hydrogen | Liquid Hydrogen

| Items | Assumptions |
|---|---|
| Central Plant Energy Efficiency: NA NG as feedstock, no Export | 71.5% |
| Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for HTGR thermo-chemcial water cracking | 2,400 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for HTGR thermo-chemcial water cracking | 50.00 |
| Energy Efficiency of coal gasification for GH2 production in central plants: without steam or electricity co-generation | 57.8% |
| Energy Efficiency of biomass gasification for GH2 production in central plants: without steam or electricity co-generation | 51.0% |
| Refueling Stations Compression Efficiency for GH2 received from Central Plants: NG Compressors | 85.0% |
| Refueling Stations Compression Efficiency for GH2 received from Central Plants: Electric Compressors | 92.5% |
| Refueling Stations Compression Efficiency for station produced GH2: NG compressors | 86.0% |
| Refueling Stations Compression Efficiency for Station produced GH2: Electric Compressors | 94.0% |
| Refueling Station Compression Efficiency for GH2 via Electrolysis: NG compressors | 86.0% |
| Refueling Station Compression Efficiency for GH2 via Electrolysis: Electric compressors | 94.0% |
| Refueling Station Production Efficiency: NA NG as feedstock | 70.5% |
| Refueling Station Production Efficiency: GH2 via Electrolysis | 71.5% |
| Refueling Station Production Efficiency: EtOH as feedstock | 47.7% |
| Refueling Station Production Efficiency: MeOH as feedstock | 50.7% |

Continue >>

**FIGURE 4.6 Key parametric assumptions for production of $GH_2$**

### 4.6.1 NG-Based $GH_2$ Production

NG-based $GH_2$ can be produced in central plants and at refueling stations. The default energy efficiencies, steam/electricity credits, and energy use for carbon sequestration in 2010 are shown in Tables 4.21 through 4.24, respectively.

**TABLE 4.21 Default Energy Efficiencies for NG-Based $GH_2$ Production in Central Plants**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 71.5% | 69.5% | 71.5% | 69.5% | 71.5% | 69.5% |

[a] North American
[b] non-North American

**TABLE 4.22 Default Steam Credit (Btu/mmBtu of $H_2$ produced) or Electricity Credit (kWh/mmBtu of $H_2$ produced) for Central NG-Based $GH_2$ Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 145,000 | 12.75 | 145,000 | 12.75 | 145,000 | 12.75 |

[a] North American
[b] non-North American

**TABLE 4.23 Default Energy Efficiencies for NG-Based $GH_2$ Production at Refueling Stations**

| Year | Feedstock: NA[a] NG | Feedstock: NNA[b] NG | Feedstock: NNA[b] FG |
|---|---|---|---|
| 2010 | 70.0% | 70.0% | 70.0% |

[a] North American
[b] non-North American

**TABLE 4.24 Default Energy Use of Carbon Sequestration for Central $GH_2$ Production**

| Year | Energy use: kWh/ton of C captured | | |
|---|---|---|---|
| | Feedstock: NG | Feedstock: coal | Feedstock: biomass |
| 2010 | 300.0 | 300.0 | 300.0 |

### 4.6.2 Nuclear-Based $GH_2$ Production

The default electricity use in the uranium enrichment processes for $GH_2$ production via thermo-chemical water cracking in 2010 is shown in Table 4.25. The default nuclear $H_2$ production rate is 29.7 mmBtu of $H_2$/g of $^{235}U$, which is set to be consistent with the electricity generation intensity from HTGR (see Table 4.20).

**TABLE 4.25 Default Electricity Use in Uranium Enrichment Process for $GH_2$ Production**

| Year | Electricity use of uranium enrichment for HTGR thermo-chemical water cracking | |
|---|---|---|
| | Gaseous diffusion | Centrifuge |
| 2010 | 2,400 | 50 |

### 4.6.3 Coal-Based $GH_2$ Production

GREET assumes that coal-based $GH_2$ is produced in central plants via gasification. The energy efficiencies and electricity credits for coal-based $GH_2$ production are shown in Table 4.26. Energy use for carbon sequestration is shown in Table 4.24.

Bituminous coal and sub-bituminous coal are two dominant coal types in the US, which contribute to 56% and 36% of total coal consumption, respectively (based on EIA data 1997–2001). Due to their different coal specifications, key parameters such as energy efficiency and electricity credit may vary between these two types of coal. Key parameters by coal type in 2010 are shown in Table 4.26. The default data in the GREET are based on bituminous coal as feedstock.

**TABLE 4.26 Energy Efficiencies and Electricity Credit for Coal-Based $GH_2$ Production**

| | Feedstock: bituminous coal | | | Feedstock: sub-bituminous coal | | |
|---|---|---|---|---|---|---|
| | Energy efficiency | | Electricity credit: kWh/mmBtu of $H_2$ | Energy efficiency | | Electricity credit: kWh/mmBtu of $H_2$ |
| Year | no kWh export | with kWh export | | no kWh export | with kWh export | |
| 2010 | 61.0% | 53.3% | 48.9 | 60.6% | 52.4% | 56.0 |

### 4.6.4 Biomass-Based $GH_2$ Production

GREET assumes that biomass-based $GH_2$ is produced in central plants via gasification. The default energy efficiencies and electricity credits for biomass-based $GH_2$ production in 2010 are shown in Table 4.27. Energy use for carbon sequestration is shown in Table 4.24.

**TABLE 4.27 Default Energy Efficiencies and Electricity Credit for Biomass-Based $GH_2$ Production**

| Year | Energy efficiency | | Electricity credit: kWh/mmBtu of $H_2$ |
|---|---|---|---|
| | no kWh export | with kWh export | |
| 2010 | 51.0% | 47.5% | 34.20 |

### 4.6.5 Refueling Station $GH_2$ Production Pathways via Electrolysis, Ethanol Reforming, and Methanol Reforming

**In addition to NG-based $H_2$ production at refueling stations, there are three more refueling station $H_2$ production pathways that can be modeled in GREET:**

- $H_2$ production via electrolysis
- $H_2$ production from reforming of ethanol
- $H_2$ production from reforming of methanol

The default energy efficiencies for these three $H_2$ production pathways in 2010 are presented in Table 4.28.

Currently, the methanol-based $H_2$ production pathway is placeholder in GREET, i.e., the model structure is completely in place for this specific fuel pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers. Efforts are continued to search for data in publicly available sources.

**TABLE 4.28 Default Energy Efficiencies for Refueling Station $GH_2$ Production Pathways**

| Year | Electrolysis | Feedstock: EtOH | Feedstock: MeOH[a] |
|---|---|---|---|
| 2010 | 71.5% | 50.0% | 50.0% |

[a] Placeholder default values

### 4.6.6 $GH_2$ Compression

The default energy efficiencies for $H_2$ compression by NG compressor or electric compressor in 2010 are shown in Table 4.29. These efficiencies are estimated with a formula to compute the compression energy requirement. In this GREET version, $GH_2$ is assumed to be stored onboard FCVs at pressures of 5,000 psi and that $GH_2$ is compressed to 6,000 psi at refueling stations. For station-produced $GH_2$, an initial pressure of 500 psi is assumed for compression. For centrally produced $GH_2$ that is transported via pipeline to refueling stations, an initial pressure of 250 psi is assumed for compression.

**TABLE 4.29 Default Energy Efficiencies for $H_2$ Compression at Refueling Stations**

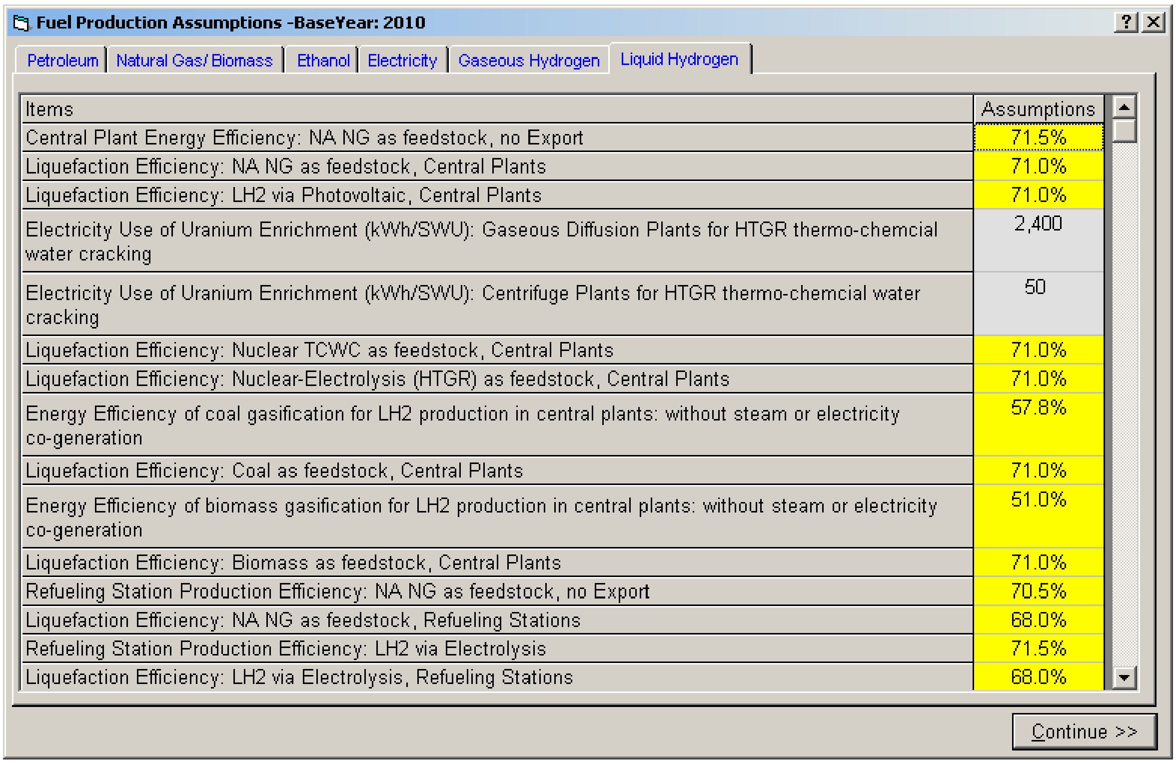
| | $H_2$ pipelined from central plants to stations | | $H_2$ produced at stations | | $H_2$ via electrolysis at stations | |
|---|---|---|---|---|---|---|
| Year | NG compressor | Electric compressor | NG compressor | Electric compressor | NG compressor | Electric compressor |
| 2010 | 85.0% | 92.5% | 86.0% | 94.0% | 86.0% | 94.0% |

## 4.7 Key Parameters for Liquid $H_2$ Production Pathways

Energy efficiencies for $LH_2$ production from various feedstock sources, steam/electricity credits, energy use for $CO_2$ sequestration, and $H_2$ liquefaction efficiencies are key parameters that can specify for $LH_2$ production pathways in the GREETGUI as shown in Figure 4.7. Depending on the selection of different $GH_2$ feedstock sources or production sites, these assumptions may change over time. Therefore, time-series tables were built in GREET for each $H_2$ production process. The same discussion of key parameters for $GH_2$ production pathways, in section 4.6 above, applies for the $H_2$ production pathways. The only difference is that $H_2$ goes through liquefaction rather than compression in $LH_2$ pathways.

### 4.7.1 NG-Based $LH_2$ Production

NG-based $LH_2$ can be produced in central plants and at refueling stations. The default energy efficiencies for $H_2$ production, liquefaction, steam/electricity credits and energy use for carbon sequestration in 2010 are shown in Tables 4.30 through 4.35, respectively.




| Items | Assumptions |
|---|---|
| Central Plant Energy Efficiency: NA NG as feedstock, no Export | 71.5% |
| Liquefaction Efficiency: NA NG as feedstock, Central Plants | 71.0% |
| Liquefaction Efficiency: LH2 via Photovoltaic, Central Plants | 71.0% |
| Electricity Use of Uranium Enrichment (kWh/SWU): Gaseous Diffusion Plants for HTGR thermo-chemcial water cracking | 2,400 |
| Electricity Use of Uranium Enrichment (kWh/SWU): Centrifuge Plants for HTGR thermo-chemcial water cracking | 50 |
| Liquefaction Efficiency: Nuclear TCWC as feedstock, Central Plants | 71.0% |
| Liquefaction Efficiency: Nuclear-Electrolysis (HTGR) as feedstock, Central Plants | 71.0% |
| Energy Efficiency of coal gasification for LH2 production in central plants: without steam or electricity co-generation | 57.8% |
| Liquefaction Efficiency: Coal as feedstock, Central Plants | 71.0% |
| Energy Efficiency of biomass gasification for LH2 production in central plants: without steam or electricity co-generation | 51.0% |
| Liquefaction Efficiency: Biomass as feedstock, Central Plants | 71.0% |
| Refueling Station Production Efficiency: NA NG as feedstock, no Export | 70.5% |
| Liquefaction Efficiency: NA NG as feedstock, Refueling Stations | 68.0% |
| Refueling Station Production Efficiency: LH2 via Electrolysis | 71.5% |
| Liquefaction Efficiency: LH2 via Electrolysis, Refueling Stations | 68.0% |

**FIGURE 4.7 Key parametric assumptions for production of $LH_2$**

**TABLE 4.30 Default Energy Efficiencies for NG-Based $H_2$ Production in Central Plants**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export | no steam or kWh export | with steam or kWh export |
| 2010 | 71.5% | 69.5% | 71.5% | 69.5% | 71.5% | 69.5% |

[a] North American
[b] non-North American

**TABLE 4.31 Default Energy Efficiencies for $H_2$ Liquefaction in Central Plants**

| Year | NA[a] NG | NNA[b] NG | NNA[b] FG |
|---|---|---|---|
| 2010 | 71.0% | 71.0% | 71.0% |

[a] North American
[b] non-North American

**TABLE 4.32 Default Steam Credit (Btu/mmBtu of $LH_2$) or Electricity Credit (kWh/mmBtu of $LH_2$) for Central NG-Based $LH_2$ Production**

| Year | Feedstock: NA[a] NG | | Feedstock: NNA[b] NG | | Feedstock: NNA[b] FG | |
|---|---|---|---|---|---|---|
| | Steam | Electricity | Steam | Electricity | Steam | Electricity |
| 2010 | 145,000 | 12.75 | 145,000 | 12.75 | 145,000 | 12.75 |

[a] North American
[b] non-North American

**TABLE 4.33 Default Energy Efficiencies for NG-Based $H_2$ Production at Refueling Stations**

| Year | Feedstock: NA[a] NG | Feedstock: NNA[b] NG | Feedstock: NNA[b] FG |
|---|---|---|---|
| 2010 | 70.0% | 70.0% | 70.0% |

[a] North American
[b] non-North American

**TABLE 4.34 Default Energy Efficiencies for $H_2$ Liquefaction at Refueling Stations**

| Year | NA[a] NG | NNA[b] NG | NNA[b] FG |
|---|---|---|---|
| 2010 | 68.0% | 68.0% | 68.0% |

[a] North American
[b] non-North American

**TABLE 4.35 Default Energy Use of Carbon Sequestration for $LH_2$ Production**

| Year | Energy use: kWh/ton of C captured | | |
|---|---|---|---|
| | Feedstock: NG | Feedstock: coal | Feedstock: biomass |
| 2010 | 300.0 | 300.0 | 300.0 |

### 4.7.2 Nuclear-Based $LH_2$ Production

Electricity use in the uranium enrichment processes for $LH_2$ production via thermo-chemical water cracking is same as that for $GH_2$ production, as explained in section 4.6.2 and Table 4.25.

Default energy efficiencies for $H_2$ liquefaction in nuclear-based $LH_2$ central plant in 2010 are shown in Table 4.36.

**TABLE 4.36 Default Energy Efficiencies for $H_2$ Liquefaction in Central Plants**

| Year | Nuclear: thermo-chemical water cracking | Nuclear: high temperature electrolysis | Coal | Solar | Biomass |
|---|---|---|---|---|---|
| 2010 | 71.0% | 71.0% | 71.0% | 71.0% | 71.0% |

### 4.7.3 Coal-Based $LH_2$ Production

GREET assumes that coal-based $LH_2$ is produced in central plants via gasification. The energy efficiencies and electricity credits for coal-based $LH_2$ production in 2010 are shown in Table 4.37. Energy efficiency for $H_2$ liquefaction in coal-based $LH_2$ central plants is shown in Table 4.36. Energy use for carbon sequestration is shown in Table 4.35.

Bituminous coal and sub-bituminous coal are two dominant coal types in the US, which contribute to 56% and 36% of total coal consumption, respectively (based on EIA data 1997–2001). Due to their different coal specifications, key parameters such as energy efficiency and electricity credits may vary between these two types of coal. Key parameters by coal type in 2010 are shown in Table 4.37. The default data in GREET are based on bituminous coal as feedstock.

**TABLE 4.37 Default Energy Efficiencies and Steam Credit for Coal-Based $H_2$ Production**

| | Feedstock: bituminous coal | | | Feedstock: sub-bituminous coal | | |
|---|---|---|---|---|---|---|
| | Energy efficiency | | | Energy efficiency | | |
| Year | no kWh export | with kWh export | Electricity credit: kWh/mmBtu of $H_2$ | no kWh export | with kWh export | Electricity credit: kWh/mmBtu of $H_2$ |
| 2010 | 61.0% | 53.3% | 48.9 | 60.6% | 52.4% | 56.0 |

### 4.7.4 Biomass-Based $LH_2$ Production

GREET assumes that biomass-based $LH_2$ is produced in central plants via gasification. The default energy efficiencies and electricity credits in 2010 are shown in Table 4.38. Energy efficiency for $H_2$ liquefaction in biomass-based $LH_2$ central plants is shown in Table 4.36. Energy use for carbon sequestration is shown in Table 4.35.

**TABLE 4.38 Default Energy Efficiencies and Electricity Credit for Biomass-Based $LH_2$ Production**

| Year | Energy efficiency | | Electricity credit: kWh/mmBtu of $H_2$ |
|---|---|---|---|
| | no kWh export | with kWh export | |
| 2010 | 51.0% | 47.5% | 34.20 |

### 4.7.5 Refueling Station $LH_2$ Production Pathways via Electrolysis, Ethanol Reforming, and Methanol Reforming

**In addition to NG-based $LH_2$ production at refueling stations, there are three additional refueling station $H_2$ production pathways that can be modeled in GREET:**

- $H_2$ production via electrolysis
- $H_2$ production from reforming of ethanol
- $H_2$ production from reforming of methanol

The default energy efficiencies for these three $H_2$ production pathways in 2010 are shown in Table 4.39. Default energy efficiencies for $H_2$ liquefaction in 2010 are shown in Table 4.40.

Currently, the methanol-based $H_2$ production pathway is placeholder in GREET, i.e., the model structure is complete for this specific fuel pathway, but the parameter values are unknown. Therefore, you should exercise caution when using the GREET default numbers. Efforts are underway to search for data in publicly available sources.

**TABLE 4.39 Default Energy Efficiencies for Refueling Station $LH_2$ Production Pathways**

| Year | Electrolysis | Feedstock: EtOH | Feedstock: MeOH[a] |
|---|---|---|---|
| 2010 | 71.5% | 50.0% | 50.0% |

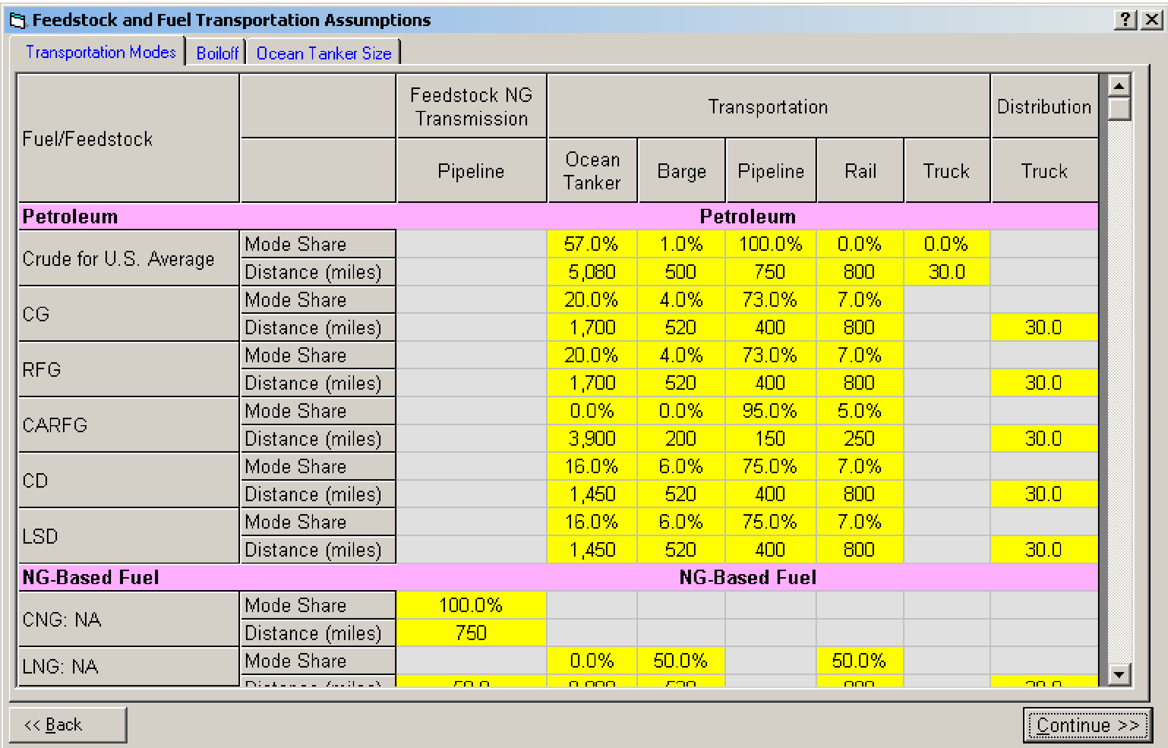
[a] Placeholder default values

**TABLE 4.40 Default Energy Efficiencies for $H_2$ Liquefaction at Refueling Stations**

| Year | Electrolysis | EtOH | MeOH |
|---|---|---|---|
| 2010 | 68.0% | 68.0% | 68.0% |

## 4.8 Key Parameters for Fuel Transportation, Distribution, and Storage

In GREET, transportation-related activities are simulated using input parameters such as transportation modes, transportation distances and energy use intensities (in Btu/ton-mi) for various modes of transportation. These parameters, which you can specify as shown in Figure 4.8, are discussed in the following subsections.


Feedstock and Fuel Transportation Assumptions
Transportation Modes | Boiloff | Ocean Tanker Size

| Fuel/Feedstock | | Feedstock NG Transmission | Transportation | | | | | Distribution |
|---|---|---|---|---|---|---|---|---|
| | | Pipeline | Ocean Tanker | Barge | Pipeline | Rail | Truck | Truck |
| **Petroleum** | | | | | **Petroleum** | | | |
| Crude for U.S. Average | Mode Share | | 57.0% | 1.0% | 100.0% | 0.0% | 0.0% | |
| | Distance (miles) | | 5,080 | 500 | 750 | 800 | 30.0 | |
| CG | Mode Share | | 20.0% | 4.0% | 73.0% | 7.0% | | |
| | Distance (miles) | | 1,700 | 520 | 400 | 800 | | 30.0 |
| RFG | Mode Share | | 20.0% | 4.0% | 73.0% | 7.0% | | |
| | Distance (miles) | | 1,700 | 520 | 400 | 800 | | 30.0 |
| CARFG | Mode Share | | 0.0% | 0.0% | 95.0% | 5.0% | | |
| | Distance (miles) | | 3,900 | 200 | 150 | 250 | | 30.0 |
| CD | Mode Share | | 16.0% | 6.0% | 75.0% | 7.0% | | |
| | Distance (miles) | | 1,450 | 520 | 400 | 800 | | 30.0 |
| LSD | Mode Share | | 16.0% | 6.0% | 75.0% | 7.0% | | |
| | Distance (miles) | | 1,450 | 520 | 400 | 800 | | 30.0 |
| **NG-Based Fuel** | | | | | **NG-Based Fuel** | | | |
| CNG: NA | Mode Share | 100.0% | | | | | | |
| | Distance (miles) | 750 | | | | | | |
| LNG: NA | Mode Share | | 0.0% | 50.0% | | 50.0% | | |

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**FIGURE 4.8 Feedstock and fuels transportation modes and distances**

### 4.8.1 Transportation Mode and Distance

**GREET includes the following modes of transportation:**

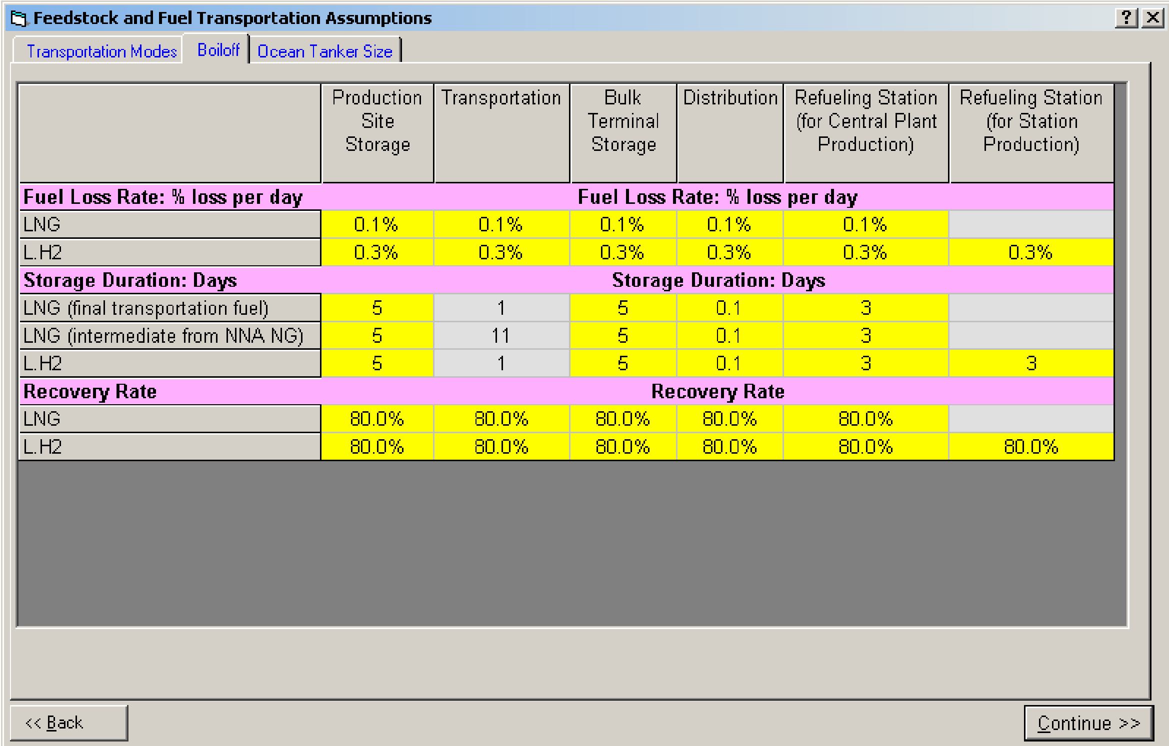
- Ocean tankers for crude oil, gasoline, diesel, LPG, LNG, methanol, FTD, naphtha, DME, and $LH_2$
- Barges for crude oil, gasoline, diesel, LPG, LNG, methanol, FTD, naphtha, DME, $LH_2$, ethanol, and biodiesel
- Pipelines for crude oil, gasoline, diesel, LPG, FTD, DME, naphtha, biodiesel, NG, and $GH_2$
- Rails for gasoline, diesel, LPG, LNG, methanol, ethanol, FTD, naphtha, DME, $LH_2$, and biodiesel
- Trucks for delivering liquid fuels from bulk terminals to refueling stations

As shown in Figure 4.8, you can specify shares of transportation mode and transportation distance for each mode. Note that the total percentage of all transportation modes may exceed 100% for some fuels, because more than one mode may be involved in transporting the fuel sequentially from the production site to the bulk terminal.

For details on methodologies and data sources, please refer to the SAE paper 2000-01-2976: *Contribution of Feedstock and Fuel Transportation to Total Fuel-cycle Energy Use and Emissions* (He and Wang, 2000). Available at http://www.sae.org/servlets/productDetail?PROD_TYP=PAPER&PROD_CD=2000-01-2976.

### 4.8.2 LNG and $LH_2$ Boil-Off

GREET allows you to specify the boil-off rate, duration of storage, and recovery rate of boil-off gas for LNG and $LH_2$, as shown in Figure 4.9. The duration data for LNG and $LH_2$ transportation are calculated based on transportation mode share and distance specified for LNG and $LH_2$, and therefore, cannot be changed (see grey cells in Figure 4.9).



Feedstock and Fuel Transportation Assumptions

Transportation Modes | Boiloff | Ocean Tanker Size

| | Production Site Storage | Transportation | Bulk Terminal Storage | Distribution | Refueling Station (for Central Plant Production) | Refueling Station (for Station Production) |
|---|---|---|---|---|---|---|
| **Fuel Loss Rate: % loss per day** | | | **Fuel Loss Rate: % loss per day** | | | |
| LNG | 0.1% | 0.1% | 0.1% | 0.1% | 0.1% | |
| L.H2 | 0.3% | 0.3% | 0.3% | 0.3% | 0.3% | 0.3% |
| **Storage Duration: Days** | | | **Storage Duration: Days** | | | |
| LNG (final transportation fuel) | 5 | 1 | 5 | 0.1 | 3 | |
| LNG (intermediate from NNA NG) | 5 | 11 | 5 | 0.1 | 3 | |
| L.H2 | 5 | 1 | 5 | 0.1 | 3 | 3 |
| **Recovery Rate** | | | **Recovery Rate** | | | |
| LNG | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% | |
| L.H2 | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% | 80.0% |

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**FIGURE 4.9 LNG and $LH_2$ boil-off data**

### 4.8.3 Cargo Payload of Ocean Tanker

You can specify cargo payload of ocean tankers for some transportation fuels, as shown in Figure 4.10.

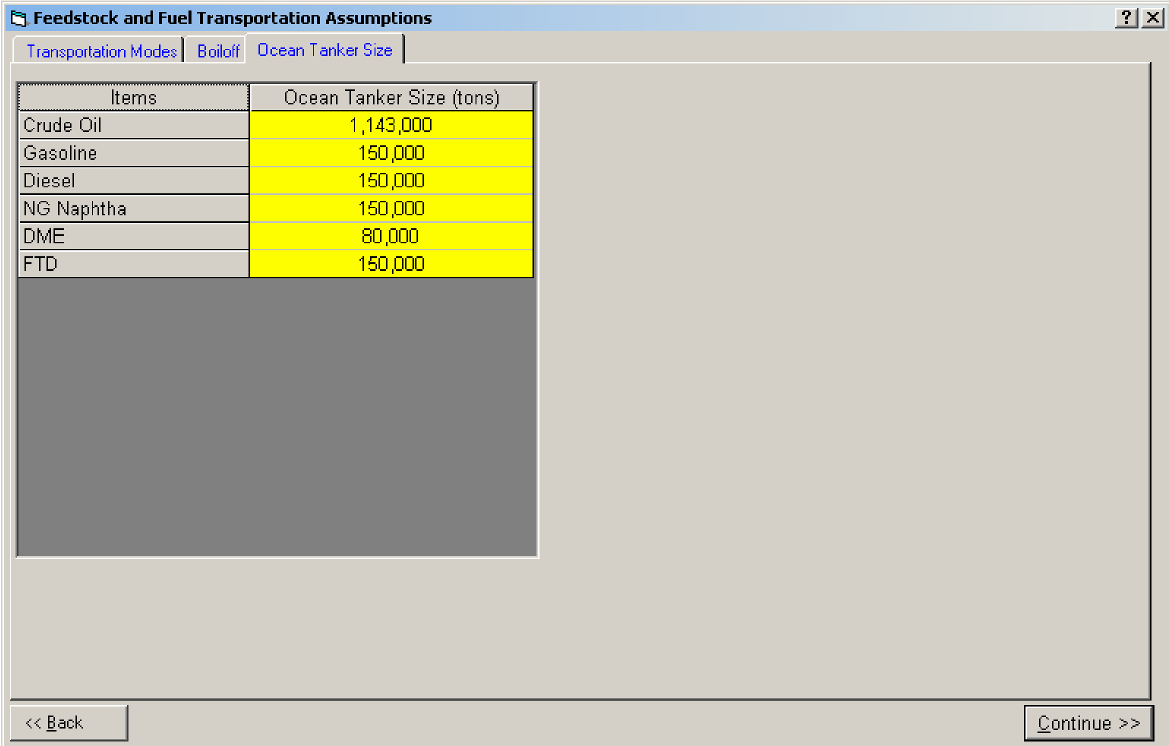



**FIGURE 4.10 Ocean tanker size**

## 4.9 Key Parameters for Vehicle Operations

In GREET, fuel economy and emissions rates of criteria air pollutants (VOC, CO, $NO_X$, $PM_{10}$) and greenhouse gases ($CH_4$ and $N_2O$) are key input parameters for the vehicle operation stage that you can specify in GREETGUI as shown in Figures 4.11 and 4.12. These parameters are used to simulate the pump-to-wheels (PTW) energy use and emissions associated with each individual vehicle/fuel system.

**Currently, only light-duty vehicles are simulated in GREET. They include:**

- passenger cars (PC)
- light-duty trucks 1 (LDT1) with a gross vehicle weight (GVW) less than 6000 lbs
- light-duty trucks 2 (LDT2) with a GVW between 6000 and 8500 lbs

As shown in Figure 2.11, you can select any of these three vehicle classes for simulation in GREET.

More than 70 vehicle/fuel systems are simulated in the current version of GREET. Among these systems, the spark-ignition (SI) vehicle fueled with gasoline (conventional gasoline [CG] and/or reformulated gasoline [RFG]), and the compression-ignition direct-injections (CIDI) vehicle fueled with diesel (conventional diesel [CD] and/or low-sulfur diesel [LSD]) are considered baseline vehicles. All other vehicles are considered alternative-fueled vehicles (AFVs) or advanced vehicle technologies (AVTs). Since the vehicles' key parameters may change over time, time-series tables are developed in GREET for each vehicle/fuel system.

### 4.9.1 Baseline Vehicles

In GREET, baseline vehicles are SI vehicles fueled with CG and/or RFG, and CIDI vehicles fueled with CD and/or LSD. You can specify the fuel economy (mile per gallon gasoline equivalent, mpgge) and emission rates (g/mi) for the baseline vehicles in GREETGUI, as shown in Figure 4.11. The only exception is the fuel economy of CIDI baseline vehicles, which is specified as a percentage change from fuel economy of baseline SI gasoline vehicles as shown in the **Alternative-Fueled and Advanced Vehicles** tab of Figure 4.12. You cannot change the absolute value of fuel economy for the CIDI diesel baseline vehicle since it is calculated in GREET from the fuel economy of baseline gasoline vehicles along with the percentage change of the baseline diesel vehicles (relative to the baseline gasoline vehicles).

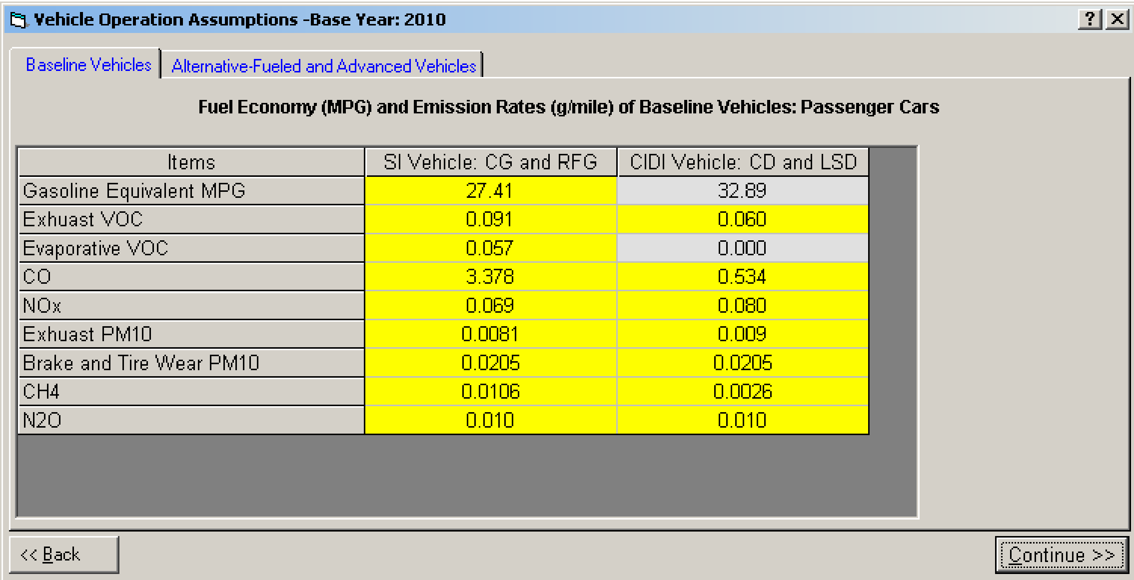
The default fuel economy data for model year 2010 SI baseline vehicles are shown in Table 4.41. The default fuel economies for model year 2010 and beyond in GREET are based on the Powertrain System Analysis Toolkit (PSAT) transient vehicle simulation software, which has been developed at the Argonne National Laboratory (ANL). Two scenarios, EIA business-as-usual technology case and FreedomCAR goals technology case, are simulated. For point-estimation simulations, values for EIA business-as-usual technology case are set as GREET defaults. For stochastic simulations, Weibull distribution functions have been developed in GREET based on the following assumptions:

- The lower fuel economy value estimated for EIA business-as-usual technology case is used as the P10 value for the Weibull distribution.
- The higher emission rate value estimated for FreedomCAR goals technology case is used as the P90 value for the Weibull distribution.
- The average of these two is set as the P50 value for the Weibull distribution.

Because there are several subclasses for each vehicle class, for example, the passenger car class includes sub-compact car, compact car, midsize car, large car, etc.; the fuel economy data may vary by the vehicle subclass.

**The default vehicle sub-classes in GREET (shown in Table 4.41), which reflect the dominant vehicle types in the current U.S. market are:**

- midsize passenger car
- midsize SUV (LDT1)
- large pickup truck (LDT2)




| Items | SI Vehicle: CG and RFG | CIDI Vehicle: CD and LSD |
|---|---|---|
| Gasoline Equivalent MPG | 27.41 | 32.89 |
| Exhuast VOC | 0.091 | 0.060 |
| Evaporative VOC | 0.057 | 0.000 |
| CO | 3.378 | 0.534 |
| NOx | 0.069 | 0.080 |
| Exhaust PM10 | 0.0081 | 0.009 |
| Brake and Tire Wear PM10 | 0.0205 | 0.0205 |
| CH4 | 0.0106 | 0.0026 |
| N2O | 0.010 | 0.010 |

**FIGURE 4.11 Fuel economy and emission rates of baseline vehicles**

**TABLE 4.41 Default Fuel Economy of SI Baseline Vehicles for Model-Year 2010 (mpgge)**

| **SI Vehicle: CG and/or RFG EIA business-as-usual technology case** | | | **SI Vehicle: CG and/or RFG FreedomCAR goals technology case** | | |
|---|---|---|---|---|---|
| **PC** | **LDT1** | **LDT2** | **PC** | **LDT1** | **LDT2** |
| 25.1 | 20.6 | 17.1 | 29.2 | 23.6 | 19.8 |

The default emission rates of the model year 2010 baseline vehicles are shown in Table 4.42. The default emission rates of $N_2O$ are derived with data available from the U.S. Environmental Protection Agency (EPA). The emission rates for VOC, CO, $NO_X$, $PM_{10}$ and $CH_4$ are simulated with the EPA's MOBILE 6.2 emission factor model and with the California Air Resource Board (CARB)'s EMFAC2002 motor vehicle emission factor model. These two available models produce quite different emission rates for the same vehicle technology. An arbitrary selection of one over the other for the emission rates estimates may not be justified.

Therefore, the GREET default emission rates are the average of the results obtained from the MOBILE 6.2 model and the EMFAC2002 model. For stochastic simulations, Weibull distribution functions have been developed in GREET based on the following assumptions:

- The lower emission rate value estimated by any one of the two models (e.g., EMFAC2002 for exhaust VOC) is used as the P10 value for the Weibull distribution; and
- The higher emission rate value estimated by the other model (e.g., MOBILE 6.2 for exhaust VOC) is used as the P90 value for the Weibull distribution.

You may load the "Stochastic Simulation" toolbar in the GREET model to generate stochastic results rather than a point estimate for any of the results forecast cells.

**TABLE 4.42 Default Emission Rates for Baseline Vehicles for Model-Year 2010 (g/mi)**

| | SI passenger car: CG and/or RFG | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Baseline Vehicle** | **Exhaust VOC** | **Evaporative VOC** | **CO** | **$NO_X$** | **Exhaust $PM_{10}$** | **TBW[a] $PM_{10}$** | **$CH_4$** | **$N_2O$** |
| Gasoline car | 0.095 | 0.057 | 3.492 | 0.069 | 0.0081 | 0.0205 | 0.0106 | 0.012 |
| Diesel car | 0.060 | 0.000 | 0.534 | 0.080 | 0.0090 | 0.0205 | 0.0026 | 0.012 |
| Gasoline LDT1 | 0.115 | 0.067 | 3.448 | 0.099 | 0.0122 | 0.0205 | 0.0126 | 0.012 |
| Diesel LDT1 | 0.063 | 0.000 | 0.409 | 0.122 | 0.0139 | 0.0205 | 0.0029 | 0.012 |
| Gasoline LDT2 | 0.143 | 0.076 | 4.074 | 0.134 | 0.0153 | 0.0205 | 0.0155 | 0.012 |
| Diesel LDT2 | 0.069 | 0.000 | 0.285 | 0.165 | 0.0188 | 0.0205 | 0.0032 | 0.012 |

[a] TBW: tire and brake wear

### 4.9.2 Alternative-Fueled and Advanced Technology Vehicles

Other than baseline vehicle/fuel systems, about 70 vehicle/fuel systems are simulated in the current GREET version.

**There are nine vehicle technologies in GREET:**

- SI vehicles (e.g., LPG, E85, and others)
- CIDI vehicles (e.g., DME, FTD, and others)
- Spark-ignition direct-injection (SIDI) vehicles (e.g., gasoline, E90, and others)
- Grid-independent (GI) SI HEVs (e.g., gasoline, CNG, and others)
- GI CIDI hybrid electric vehicles (HEVs) (e.g., diesel, FTD, and others)
- Grid-connected (GC) SI HEVs (e.g., gasoline, E90, and others)
- GC CIDI HEVs (e.g., diesel, FTD, and others)
- Fuel cell vehicles (FCVs) (e.g., $H_2$, ethanol, and others)
- Electric vehicles (EVs) fueled with different electricity generation mixes

As shown in Figure 4.12, **you can specify the change rates of:**

- fuel economy (relative to the baseline SI gasoline vehicle)
- emission factors (SI technologies relative to the baseline SI gasoline vehicle and CIDI technologies relative to the baseline CIDI diesel vehicle) for alternative-fueled vehicles and advanced vehicle technologies.

The absolute values of fuel economies and emission rates are automatically calculated with the estimated relative change rates along with the fuel economy and emission rates of the baseline vehicles.

The default change rates relative to the baseline vehicles are estimated from a multiple data sources, such as testing results or engineering analysis, which may change over time. The default change rates for these model year 2010 alternative-fueled and advanced technology vehicles are shown in Tables 4.43 and 4.44.

Note that many vehicle technologies are for use in the future, not yet available in the historical U.S. market. In GREET, these vehicle technology options: (1) $H_2$ SI ICE vehicles, (2) SIDI vehicles, (3) GI SI HEVs, (4) GC SI HEVs, (5) GI CIDI HEVs, (6) GC CIDI HEVs, and (7) Fuel-cell vehicles, can be only simulated for model-year 2005 and after.

**Vehicle Operation Assumptions -Base Year: 2010**

Baseline Vehicles | Alternative-Fueled and Advanced Vehicles

**MPG and Emission Ratios for Alternative-Fueled and Advanced Vehicles RELATIVE TO Baseline Vehicles: Passenger Cars**

| Items | CIDI Vehicle: CD and LSD | SI Vehicle: Dedicated CNGV | SI Vehicle: Dedicated LNGV | SI Vehicle: Dedicated LPGV | SI Vehicle: Dedi. MeOH Vehicle | SI Vehicle: EtOH Low-Level | SI Vehicle: EtOH FFV |
|---|---|---|---|---|---|---|---|
| Gasoline Equivalent MPG | 120.0% | 105.0% | 105.0% | 107.0% | 107.0% | 100.0% | 105.0% |
| Exhaust VOC | | 90.0% | 90.0% | 100.0% | 100.0% | 100.0% | 85.0% |
| Evaporative VOC | | 5.0% | 5.0% | 5.0% | 100.0% | 100.0% | 85.0% |
| CO | | 60.0% | 60.0% | 60.0% | 100.0% | 100.0% | 75.0% |
| NOx | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 90.0% |
| Exhaust PM10 | | 20.0% | 20.0% | 20.0% | 60.0% | 100.0% | 40.0% |
| Brake and Tire Wear PM10 | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| CH4 | | 500.0% | 500.0% | 110.0% | 50.0% | 100.0% | 150.0% |
| N2O | | 50.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% |

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**FIGURE 4.12 Fuel economy and emission change rates by alternative-fueled and advanced technology vehicles relative to baseline vehicles**

**TABLE 4.43 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology PC/LDT1 Relative to Baseline PC/LDT1**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **SI vehicle: CARFG** | | | | | | | | |
| 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: bi-fuel CNGV** | | | | | | | | |
| 92.5% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: MeOH FFV** | | | | | | | | |
| 105.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: EtOH FFV** | | | | | | | | |
| 105.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: low-level EtOH blend with gasoline** | | | | | | | | |
| 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated CNGV** | | | | | | | | |
| 103.0% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: dedicated LNGV** | | | | | | | | |
| 103.0% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: dedicated LPGV** | | | | | | | | |
| 105.0% | 100.0% | 80.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated MeOH vehicle** | | | | | | | | |
| 107.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated EtOH vehicle** | | | | | | | | |
| 107.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: $H_2$** | | | | | | | | |
| 120.0% | 20.0% | 0.0% | 20.0% | 100.0% | 10.0% | 100.0% | 10.0% | 100.0% |
| **SI DI vehicle: CG and/or RFG** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: CARFG** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: low-level EtOH blend with gasoline** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: dedicated MeOH Vehicle** | | | | | | | | |
| 115.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: dedicated EtOH Vehicle** | | | | | | | | |
| 115.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

**TABLE 4.43 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology PC/LDT1 Relative to Baseline PC/LDT1 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **CIDI vehicle: CD and/or LSD** | | | | | | | | |
| 149.0% | | | | | | | | |
| **CIDI vehicle: DME** | | | | | | | | |
| 149.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 200.0% | 100.0% |
| **CIDI vehicle: FTD** | | | | | | | | |
| 149.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **CIDI vehicle: Biodiesel blends** | | | | | | | | |
| 149.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **CIDI vehicle: E-Diesel** | | | | | | | | |
| 149.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI SI HEV: CG and/or RFG** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: CARFG** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: low-level EtOH blend with gasoline** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: CNG** | | | | | | | | |
| 152.0% | 54.0% | 50.0% | 100.0% | 84.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GI SI HEV: LNG** | | | | | | | | |
| 152.0% | 54.0% | 50.0% | 100.0% | 84.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GI SI HEV: LPG** | | | | | | | | |
| 152.0% | 54.0% | 80.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: MeOH** | | | | | | | | |
| 152.0% | 54.0% | 85.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: EtOH** | | | | | | | | |
| 152.0% | 54.0% | 85.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GI SI HEV: $H_2$** | | | | | | | | |
| 162.0% | 20.0% | 0.0% | 20.0% | 84.0% | 10.0% | 100.0% | 10.0% | 100.0% |
| **GC SI HEV: CG and/or RFG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CG and/or RFG, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |

**TABLE 4.43 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology PC/LDT1 Relative to Baseline PC/LDT1 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **GC SI HEV: CARFG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CARFG, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GC SI HEV: low-level EtOH blend with gasoline, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: low-level EtOH blend with gasoline, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 100.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GC SI HEV: CNG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CNG, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 50.0% | 100.0% | 84.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GC SI HEV: LNG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: LNG, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 50.0% | 100.0% | 84.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GC SI HEV: LPG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: LPG, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 80.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GC SI HEV: MeOH, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: MeOH, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 85.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GC SI HEV: EtOH, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: EtOH, ICE mode** | | | | | | | | |
| 152.0% | 54.0% | 85.0% | 100.0% | 84.0% | 100.0% | 100.0% | 47.0% | 100.0% |
| **GC SI HEV: $H_2$, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: $H_2$, ICE mode** | | | | | | | | |
| 162.0% | 20.0% | 0.0% | 20.0% | 84.0% | 10.0% | 100.0% | 10.0% | 100.0% |

**TABLE 4.43 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology PC/LDT1 Relative to Baseline PC/LDT1 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **GI CIDI HEV: CD and/or LSD** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: DME** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 150.0% | 100.0% |
| **GI CIDI HEV: FTD** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: Biodiesel blends** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: E-Diesel** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: CD and/or LSD, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: CD and/or LSD, ICE mode** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: DME, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: DME, ICE mode** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 150.0% | 100.0% |
| **GC CIDI HEV: FTD, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: FTD, ICE mode** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: Biodiesel blends, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: Biodiesel blends, ICE mode** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: E-Diesel, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: E-Diesel, ICE mode** | | | | | | | | |
| 174.0% | 78.0% | | 100.0% | 87.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **EV** | | | | | | | | |
| 350.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |

**TABLE 4.43 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology PC/LDT1 Relative to Baseline PC/LDT1 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **FCV: $H_2$** | | | | | | | | |
| 232.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **FCV: MeOH** | | | | | | | | |
| 158.0% | 20.0% | 40.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: RFG** | | | | | | | | |
| 148.0% | 20.0% | 70.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: CARFG** | | | | | | | | |
| 148.0% | 20.0% | 70.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: LSD** | | | | | | | | |
| 148.0% | 20.0% | 0.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: EtOH** | | | | | | | | |
| 148.0% | 20.0% | 40.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: CNG** | | | | | | | | |
| 148.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 100.0% | 20.0% |
| **FCV: LNG** | | | | | | | | |
| 148.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 100.0% | 20.0% |
| **FCV: LPG** | | | | | | | | |
| 148.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: naphtha** | | | | | | | | |
| 148.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |

**TABLE 4.44 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology LDT2 Relative to Baseline LDT2**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **SI vehicle: CARFG** | | | | | | | | |
| 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: bi-fuel CNGV** | | | | | | | | |
| 92.5% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: MeOH FFV** | | | | | | | | |
| 105.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: EtOH FFV** | | | | | | | | |
| 105.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: low-level EtOH blend with gasoline** | | | | | | | | |
| 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated CNGV** | | | | | | | | |
| 103.0% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: dedicated LNGV** | | | | | | | | |
| 103.0% | 100.0% | 50.0% | 100.0% | 100.0% | 100.0% | 100.0% | 1000.0% | 100.0% |
| **SI vehicle: dedicated LPGV** | | | | | | | | |
| 105.0% | 100.0% | 80.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated MeOH vehicle** | | | | | | | | |
| 107.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: dedicated EtOH vehicle** | | | | | | | | |
| 107.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI vehicle: $H_2$** | | | | | | | | |
| 120.0% | 20.0% | 0.0% | 20.0% | 100.0% | 10.0% | 100.0% | 10.0% | 100.0% |
| **SI DI vehicle: CG and/or RFG** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: CARFG** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: low-level EtOH blend with gasoline** | | | | | | | | |
| 115.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: dedicated MeOH Vehicle** | | | | | | | | |
| 115.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **SI DI vehicle: dedicated EtOH Vehicle** | | | | | | | | |
| 115.0% | 100.0% | 85.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

**TABLE 4.44 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology LDT2 Relative to Baseline LDT2 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **CIDI vehicle: CD and/or LSD** | | | | | | | | |
| 142.0% | | | | | | | | |
| **CIDI vehicle: DME** | | | | | | | | |
| 142.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 200.0% | 100.0% |
| **CIDI vehicle: FTD** | | | | | | | | |
| 142.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **CIDI vehicle: Biodiesel blends** | | | | | | | | |
| 142.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **CIDI vehicle: E-Diesel** | | | | | | | | |
| 142.0% | 100.0% | | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI SI HEV: CG and/or RFG** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: CARFG** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: low-level EtOH blend with gasoline** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: CNG** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GI SI HEV: LNG** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GI SI HEV: LPG** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: MeOH** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: EtOH** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GI SI HEV: $H_2$** | | | | | | | | |
| 163.0% | 20.0% | 0.0% | 20.0% | 78.0% | 10.0% | 100.0% | 10.0% | 100.0% |
| **GC SI HEV: CG and/or RFG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CG and/or RFG, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |

**TABLE 4.44 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology LDT2 Relative to Baseline LDT2 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **GC SI HEV: CARFG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CARFG, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GC SI HEV: low-level EtOH blend with gasoline, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: low-level EtOH blend with gasoline, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GC SI HEV: CNG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: CNG, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GC SI HEV: LNG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: LNG, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 500.0% | 100.0% |
| **GC SI HEV: LPG, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: LPG, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GC SI HEV: MeOH, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: MeOH, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GC SI HEV: EtOH, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: EtOH, ICE mode** | | | | | | | | |
| 153.0% | 86.0% | 100.0% | 74.0% | 78.0% | 100.0% | 100.0% | 84.0% | 100.0% |
| **GC SI HEV: $H_2$, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC SI HEV: $H_2$, ICE mode** | | | | | | | | |
| 163.0% | 20.0% | 0.0% | 20.0% | 78.0% | 10.0% | 100.0% | 10.0% | 100.0% |

**TABLE 4.44 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology LDT2 Relative to Baseline LDT2 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **GI CIDI HEV: CD and/or LSD** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: DME** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 150.0% | 100.0% |
| **GI CIDI HEV: FTD** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: Biodiesel blends** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GI CIDI HEV: E-Diesel** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: CD and/or LSD, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: CD and/or LSD, ICE mode** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: DME, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: DME, ICE mode** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 150.0% | 100.0% |
| **GC CIDI HEV: FTD, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: FTD, ICE mode** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: Biodiesel blends, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: Biodiesel blends, ICE mode** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **GC CIDI HEV: E-Diesel, grid mode** | | | | | | | | |
| 300.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **GC CIDI HEV: E-Diesel, ICE mode** | | | | | | | | |
| 180.0% | 100.0% | | 100.0% | 82.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| **EV** | | | | | | | | |
| 350.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |

**TABLE 4.44 Default Change Rates by Model-Year 2010 Alternative-Fueled and Advanced Technology LDT2 Relative to Baseline LDT2 (Cont'd)**

| Fuel economy | Exhaust VOC | Evaporative VOC | CO | $NO_X$ | Exhaust $PM_{10}$ | TBW $PM_{10}$ | $CH_4$ | $N_2O$ |
|---|---|---|---|---|---|---|---|---|
| **FCV: $H_2$** | | | | | | | | |
| 189.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% |
| **FCV: MeOH** | | | | | | | | |
| 158.0% | 20.0% | 40.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: RFG** | | | | | | | | |
| 140.0% | 20.0% | 70.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: CARFG** | | | | | | | | |
| 140.0% | 20.0% | 70.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: LSD** | | | | | | | | |
| 140.0% | 20.0% | 0.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: EtOH** | | | | | | | | |
| 146.0% | 20.0% | 40.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: CNG** | | | | | | | | |
| 140.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 100.0% | 20.0% |
| **FCV: LNG** | | | | | | | | |
| 140.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 100.0% | 20.0% |
| **FCV: LPG** | | | | | | | | |
| 140.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |
| **FCV: naphtha** | | | | | | | | |
| 140.0% | 20.0% | 5.0% | 20.0% | 20.0% | 0.0% | 100.0% | 20.0% | 20.0% |

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